APPLICATION OF THE REVISED SIMPLEX METHOD TO THE FARM PLANNING MODEL

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CHAPTER I

INTRODUCTION

The Farm Planning Model is used to determine optimal allocation of a farm's limited resources such as land, labor and capital among alternative crop and livestock enterprises. It helps farmers to decide what and how much will be produced in order to make the optimal returns from the resources they have or have access to.

Farm Planning Model has been a topic of farm and agribusiness management textbooks for a number of years [Barnard79; Castle72; Herbst86; Kay94; Osburn83]. However, while these farm management textbooks include descriptions and provide graphical solutions of trivial models, methods for solving more realistic models have not been included [Epplin97].

Farm Planning Model uses linear programming method to solve the optimization problem of allocating the scarce resources to the products in a manner such that profits are a maximum, or alternatively, costs are a minimum.

Since the development of modern techniques of management, linear programming has become an important tool of economics. It assumes a prominent position in operations research and management science [Simonnard66]. Currently there are many software systems solving the linear programming problem, such as integrated linear programming solver in MS-Excel, linear programming module in MATLAB, and the

General Algebraic Modeling System (GAMS). There are also small linear programming software designed specifically for farm planning such as MUSAH86 [Li85]. All of the above mentioned software systems are relatively complex and require certain levels of computer skills and knowledge of linear algebra and agricultural economics background. For example, all of these software systems need users to set up the objective function and the constraint matrix for the farm planning problem. This kind of inconvenience prevents farmers from using these systems. In order to let the farmers solve farm planning problem themselves, an easy-to-use software system for the farm planning problem is needed. Windows-based application systems require users to have few computer skills to use these systems. The objective of this thesis is to develop a linear programming software system to solve the farm planning problem, which is both easy-to-use and user-friendly. For example, the proposed software system for the farm planning problem will set up the objective function and the constraint matrix automatically for the users. The entire software system includes four parts: the farm planning data sheets, the farm planning model, the farm planning solver and the sensitivity analysis. The farm planning data sheets allow the users to enter the relevant information of the farm planning problem (such as the amounts of resources and the prices of products and so on). The farm planning model generates the objective function and the constraint matrix for the farm planning problem automatically from the information the users enter in the farm planning data sheets. The farm planning solver solves the farm planning problem to return the optimal solution back to the same constraint matrix generated in the part of the farm planning model. This part also generates a plain text solution report which is easily understood by farmers. The optimal solution provides the users with the optimal value for the farm planning problem and its associated allocation of the products produced and the resources used. The sensitivity analysis gives the ranges of variation of coefficients (C_j) for which the optimal solution remains optimal. A plain text sensitivity analysis report is also generated. The farm planning model system is implemented using Visual Basic 5.0 under the Windows 95 environment.

CHAPTER II

SIMPLEX METHOD AND REVISED SIMPLEX METHOD: A REVIEW

As discussed in the previous chapter, linear programming is an important tool of economics and already has demonstrated its value as an aid to decision making in business, industry, and government. There are many methods used to solve the linear programming problem, such as the Graphical Method, the Systematic Trial-and-Error Method, the Vector Method, and the Simplex Method. Among these methods, the Simplex Method and its variant, the Revised Simplex Method, are the most powerful and most popular ones [Loomba64]. Simplex Method and Revised Simplex Method are described in this chapter. Sensitivity analysis is also discussed at the end of this chapter.

2.1 Simplex Method

The Simplex Method was first proposed in 1947 by G. B. Dantzig [Murtagh81]. It observes that the solution set of such linear program is convex, that is, the solution set of a linear program of n variables can be represented as a convex polygon in an n-space. This is illustrated in Figure 2.1, the shaded area is the solution set. Furthermore, if a maximum or minimum value of the solution exists, it will be at a corner of this polygonal region. The Simplex Method must visit corners of the solution set to find the maximum value. In other words, the Simplex Method is an iterative procedure for determining basic feasible solutions to a system of equations and testing each solution for optimality [Childress74]. That is, the Simplex Method begins at an arbitrary corner of the basic solution set. At each iteration, the Simplex Method selects the variable that will produce the largest change towards the maximum (minimum) solution. That variable replaces one of its components that is most severely restricting it, thus moving the Simplex Method to a different corner of the solution set and closer to the final solution. In addition, the Simplex Method can determine when no solution actually exists.

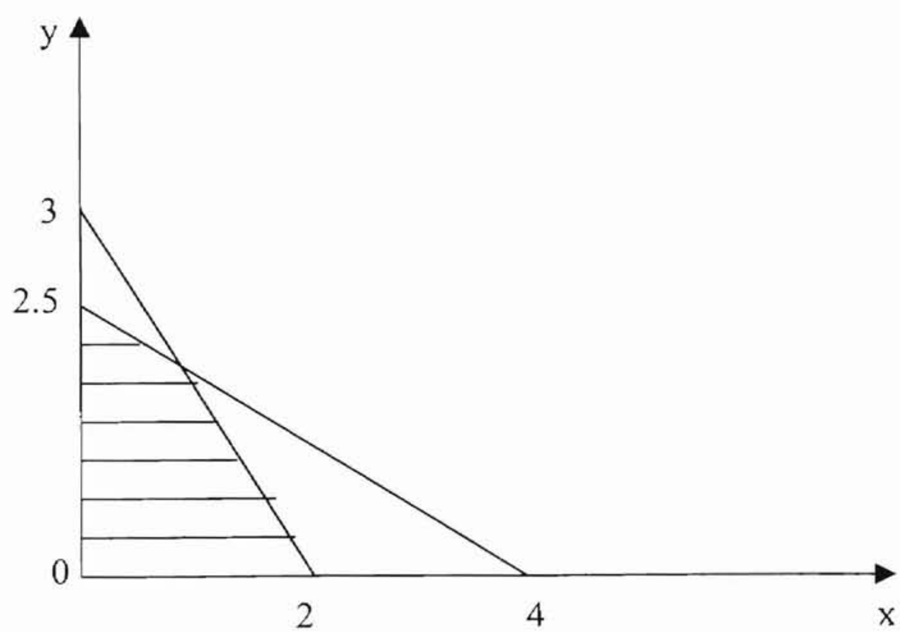

Figure 2.1 The Solution Set for the Linear Program:

$$\begin{aligned} 3x + 2y &\leq 6 \\ 5x + 8y &\leq 20 \end{aligned}$$

The general form of linear programming is formalized in (2.1).

$$\text{maximize} \qquad Z = \sum_{j=1}^{n} C_j X_j$$

$$\text{subject to:} \qquad \sum_{j=1}^{n} a_{ij} X_j \leq b_i \;\; (\, i = 1, 2, \ldots, m < n)$$

$$X_j \geq 0 \; (j = 1, 2, \ldots, n) \tag{2.1}$$

where, Z represents the value to be optimized, that is, either maximized or minimized. n is the number of activities, m is the number of potentially scarce resources. The coefficients C_j represent the marginal change in the value of the objective function Z resulting from a one unit change in activity j. The variables X_j represent a choice variable which represents the level of activity j. The solution of the model provides the "optimal" level of activity j (j = 1,2,..,n). The coefficient a_{ij} represents the input-output coefficient which indicates the amount of resource i required to produce a unit of activity j. The variable b_i represent the initial quantity of resource or other constraint b available for allocation to the alternative activities, for i = 1, 2, …, m. These statements combined represent a linear program, to which we seek a solution of optimal profit or minimum cost.

The Simplex Method operates only upon the standard form of the linear programming problem that includes inequality constraints and nonnegative variables. To solve the linear programming problem in (2.1) using the Simplex Method, we need to change (2.1) to the standard form of the linear programming by adding slack variables. A slack variable means the amount by which the left-hand-side of the inequality falls short of the right-hand-side, and it plays a very important role in the solution of linear programming problem. With the introduction of the slack variables X_{n+1}, X_{n+2}, …, X_{n+m}, the initial basic feasible solution (BFS) will be the solution of the linear program where the following holds:

$$X_j = 0 \qquad (j = 1, 2, \ldots, n)$$
$$X_j = b_{j-n} \qquad (j = n+1, n+2, \ldots, n+m)$$

where X_j ($j = 1, 2, \ldots, n$) are non-basic variables and X_j ($j = n+1, n+2, \ldots, n+m$) are basic variables (or slack variables). Once a solution to the linear program has been found, successive improvements are made to the solution. In particular, one of the nonbasic variables (with a value of zero) is chosen to be increased so that the value of the cost function, $Z = \sum_{j=1}^{n} C_j X_j$ decreases. That variable is then increased, maintaining the equality of all the equations while keeping the other nonbasic variables at zero, until one of the basic (nonzero) variables is reduced to zero and thus removed from the basis. At this point, a new solution has been determined at a different corner of the solution set. The process is then repeated with a new variable becoming basic as the other becomes nonbasic. Finally, the Simplex Method results in one of the following three situations. First, a solution may occur where no nonbasic variable will decrease the cost, in which case the current solution is the optimal solution. Second, a non-basic variable might increase to infinity without causing a basic-variable to become zero, resulting in an unbounded solution. Third, no solution may actually exist and the Simplex Method must abort [Murtagh81].

The following is a demonstration of the Simplex Method. Assume there are two activities and two resource constraints,

$$
\begin{aligned}
\text{Maximize} \quad & Z = 4X_1 + 5X_2 \\
\text{Subject to:} \quad & 1X_1 + 2X_2 \leq 40 \\
& 4X_1 + 3X_2 \leq 120 \\
& X_1, X_2 \geq 0
\end{aligned}
\tag{2.2}
$$

Rewrite (2.2) into the standard form of the linear programming by adding nonnegative slack variables X_3, X_4,

$$
\begin{aligned}
\text{maximize} \quad & Z = 4X_1 + 5X_2 + 0\,X_3 + 0\,X_4 \\
\text{Subject to:} \quad & 1X_1 + 2X_2 + 1\,X_3 = 40 \\
& 4X_1 + 3X_2 + 1\,X_4 = 120 \\
& X_1, X_2, X_3, X_4 \geq 0
\end{aligned}
\tag{2.3}
$$

The matrix or Simplex tableau of (2.3) is

	Basic Variables	RHS	X_1	X_2	X_3	X_4
C_j			4	5	0	0
0	X_3	40	1	2	1	0
0	X_4	120	4	3	0	1

The abbreviation RHS denotes the "right hand side" coefficient. To make the solution to be feasible, every entry in the RHS column must be nonnegative. The step by step sequence of operations at every iteration is as follows (Figure 2.2):

Step 1: Select the activity (column) X_c with the smallest $(Z_j - C_j)$, which contributes most to the objective function.

Step 2: For every coefficient a_{ic} in the X_c column, compute $R_i = RHS_i/a_{ic}$. Select as the variable X_r to leave the basis the one which is defined by the row with the smallest such R_i .

Step 3: Let a_{rc} denotes the "pivot" element, the coefficient at the intersection of the X_r-row and the X_c-column. For every element a_{rj} in the pivot row, the new value is

Initial solution:

	Basic Variables	R	RHS	X_1	X_2	X_3	X_4
C_j				4	5	0	0
0	X_3	20	40	1	<u>2</u>	1	0
0	X_4	40	120	4	3	0	1
	Z_j		0	0	0	0	0
	$Z_j - C_j$			-4	-5	0	0

First iteration:

5	X_2	40	20	1/2	1	1/2	0
0	X_4	24	60	<u>5/2</u>	0	-3/2	1
	Z_j		100	5/2	5	5/2	0
	$Z_j - C_j$			-3/2	0	5/2	0

Second iteration: Optimum solution

5	X_2		8	0	1	4/5	-1/5
4	X_1		24	1	0	-3/5	2/5
	Z_j		136	4	5	8/5	3/5

Figure 2.2 Simplex Method to Solve Linear Program (2.3). The optimal solution is $Z = 136, X_1 = 24, X_2 = 8$ with $X_3 = X_4 = 0$.

$a_{rj}' = a_{rj} / a_{rc}$. Let this corresponding X_r enters the basis. The pivot element at each iteration is underlined.

Step 4: Let a_{ij} denotes any element not in the pivot row and a_{ic} the element in the same row and the pivot column, the new value of a_{ij} is

$$a_{ij}' = a_{ij} - (a_{ic})(a_{rj}')$$

Step 5: If there are any negative coefficients in the $(Z_j - C_j)$ row, begin the next iteration of step 1. Otherwise terminate, a solution is found.

2.2 Revised Simplex Method

Since the Simplex Method procedure is laborious and time-consuming, researches have developed a more efficient matrix-oriented approach called the Revised Simplex Method (RSM).

The Revised Simplex Method describes linear programs as matrix entities and presents the Simplex Method as a series of linear algebra computations. Instead of spending time updating tableau at the end of each iteration, the RSM does its heavy calculation at the beginning of each iteration, resulting in much less at the end. The formulation of the Revised Simplex Method is as follows [Locks74].

$$\begin{aligned} &\text{Maximize} && Z = \mathbf{C}^T\mathbf{X} \\ &\text{Subject to:} && \mathbf{AX} \leq \mathbf{b} \\ & && \mathbf{X} \geq 0 \end{aligned} \tag{2.4}$$

where $\mathbf{C}$ is a given $n \times 1$ component vector, $\mathbf{C}^T$ is a transformation of $\mathbf{C}$, which is $1 \times n$.

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where $\mathbf{C}$ is a given $n \times 1$ component vector, $\mathbf{C}^T$ is a transformation of $\mathbf{C}$, which is $1 \times n$.

$$\mathbf{C} = \begin{bmatrix} C_1 \\ C_2 \\ . \\ . \\ . \\ C_n \end{bmatrix}, \qquad \mathbf{C}^T = \begin{bmatrix} C_1. & C_2. & . & . & . & C_n \end{bmatrix}.$$

X is an n × 1 vector of unknowns,

$$\mathbf{X} = \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_n \end{bmatrix}.$$

A is a given m × n coefficient matrix,

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & a_{2n} \\ . & & & & \\ . & & & & \\ a_{m1} & . & . & . & a_{mn} \end{bmatrix},$$

b is a given m × 1 component column vector,

$$\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ . \\ . \\ . \\ b_m \end{bmatrix}$$

and **0** is an n-component null vector.

In the RSM, $\mathbf{X}$ can be partitioned into $\mathbf{X_N}$ and $\mathbf{X_B}$, which is

$$\mathbf{X} = \left[\frac{X_N}{X_B}\right]$$

$\mathbf{X_N}$ is called the vector of nonbasic variables, $\mathbf{X_B}$ is called the vector of basic variables. That is,

$$\mathbf{X_N} = \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_n \end{bmatrix},$$

$$\mathbf{X_B} = \begin{bmatrix} X_{n+1} \\ . \\ . \\ . \\ X_{n+m} \end{bmatrix}.$$

(2.4) now becomes:

$$\begin{aligned} &\text{Maximize} && Z = \mathbf{C}^T\mathbf{X} \\ &\text{Subject to:} && [\mathbf{A}, \mathbf{I}] \begin{bmatrix} X_N \\ X_B \end{bmatrix} = \mathbf{b} \\ & && \mathbf{X} \geq \mathbf{0} \end{aligned} \tag{2.5}$$

where $\mathbf{I}$ is the m × m identity matrix. $[\mathbf{A}, \mathbf{I}]$ is the tableau of the initial iteration of the Simplex Method. The basic solution of (2.5) is an m × 1 subvector $\mathbf{X_B}$ of $\begin{bmatrix} X_N \\ X_B \end{bmatrix}$.

Associated with $\mathbf{X_B}$ is the m × m nonsingular basis matrix $\mathbf{B}$, consisting of the columns of $[\mathbf{A}, \mathbf{I}]$ associated with the basic variables. The initial basic feasible solution of the RSM becomes:

$$\mathbf{B X_B} = \mathbf{b}. \tag{2.6}$$

Since $\mathbf{B}$ is nonsingular, the basic solution for (2.6) is obtained by premultiplying both sides by $\mathbf{B}^{-1}$,

$$\mathbf{B}^{-1}\mathbf{B}\ \mathbf{X_B} = \mathbf{I}\ \mathbf{X_B} = \mathbf{X_B} = \mathbf{B}^{-1}\mathbf{b}. \tag{2.7}$$

Premultiplying both sides of (2.5) by $\mathbf{B}^{-1}$, we have the corresponding expression in terms of the entire simplex tableau,

$$\mathbf{B}^{-1}\ [\mathbf{A}, \mathbf{I}] \begin{bmatrix} X_N \\ X_B \end{bmatrix} = [\mathbf{B}^{-1}\ \mathbf{A}, \mathbf{B}^{-1}\ ] \begin{bmatrix} X_N \\ X_B \end{bmatrix} = \mathbf{B}^{-1}\ \mathbf{b}. \tag{2.8}$$

The augmented standard form of the linear programming problem includes one additional basic variable, Z, that is included in every basic solution. The augmented statement of the problem corresponding to (2. 5) is

$$\begin{bmatrix} 1 & -C & 0 \\ 0 & A & I \end{bmatrix} \begin{bmatrix} Z \\ X_N \\ X_B \end{bmatrix} = \begin{bmatrix} 0 \\ b \end{bmatrix} \tag{2.9}$$

The augmented vector of basic variables is $\begin{bmatrix} Z \\ X_B \end{bmatrix}$. Let $\mathbf{C_B}$ denote the row m-vector of objective-function coefficients for $\mathbf{X_B}$. The augmented basis matrix is

$$\mathbf{B}_0 = \begin{bmatrix} 1 & -C_B \\ 0 & B \end{bmatrix}.$$

Then the inverse of the $\mathbf{B}_0$ is

$$\mathbf{B}_0^{-1} = \begin{bmatrix} 1 & -C_B B^{-1} \\ 0 & B^{-1} \end{bmatrix}.$$

Premultiplying both sides of (2.9) by $\mathbf{B}_0^{-1}$, we therefore obtain

$$\begin{bmatrix} 1 & -C_B B^{-1} \\ 0 & B^{-1} \end{bmatrix}\begin{bmatrix} 1 & -C & 0 \\ 0 & A & I \end{bmatrix}\begin{bmatrix} Z \\ X_N \\ X_B \end{bmatrix} = \begin{bmatrix} 1 & C_B B^{-1} A - C & C_B B^{-1} \\ 0 & B^{-1} A & B^{-1} \end{bmatrix}\begin{bmatrix} Z \\ X_N \\ X_B \end{bmatrix} = \begin{bmatrix} C_B B^{-1} b \\ B^{-1} b \end{bmatrix}$$

(2.10)

The equation (2.10) shows that for every iteration the entire simplex tableau is a function of $\mathbf{B}^{-1}$, which is m × m submatrix formed by the slack-variable columns.

There are several ways of making the change-of-basis calculations from one iteration to the next. A simpler method, which used in the RSM, is to identify the basis matrix **B** as the submatrix of **[A, I]**, associated with the basic solution $\mathbf{X}_B$, and invert it to get $\mathbf{B}^{-1}$, and premultiply it by an elementary transformation matrix, E. E is identical to an identity matrix except for one column, called the η-vector.

Let a_{ij}, i= 1, …, m, j=1, …, n, n+1, …, n+m, denotes any coefficient of the submatrix $[\mathbf{B}^{-1}\mathbf{A}, \mathbf{B}^{-1}]$ of the simplex tableau, and suppose that at the current iteration X_r leaves the basis and X_k enters, then a_{rk} is the "pivot" element. The η-vector is

$$\eta = \frac{1}{a_{rK}}\begin{bmatrix} -a_{1K} \\ \cdot \\ \cdot \\ 1 \\ \cdot \\ \cdot \\ -a_{mK} \end{bmatrix},$$

where the number 1 denotes the r-th row. The E matrix is the identity matrix with the r-th column replaced by the η-vector. The new $\mathbf{B}^{-1}$ is obtained simply by,

$$B_{new}^{-1} = \mathbf{E}\ B_{old}^{-1}.$$

To solve the linear prgramming problem in (2.2) using the RSM, it is to,

$$\text{Maximize } [\,4,\ 5]\begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

$$\text{subject to } \begin{bmatrix} 1 & 2 \\ 4 & 3 \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \le \begin{bmatrix} 40 \\ 120 \end{bmatrix}$$

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \ge 0 \tag{2.11}$$

The augmented standard form of (2.11) is

$$\begin{bmatrix} 1 & -4 & -5 & 0 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 4 & 3 & 0 & 1 \end{bmatrix}\begin{bmatrix} Z \\ X_1 \\ \cdot \\ \cdot \\ X_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 40 \\ 120 \end{bmatrix}$$

with $\mathbf{X}_B = \begin{bmatrix} X_3 \\ X_4 \end{bmatrix}$.

At the first iteration, X_2 enters the basis, it replaces X_3, the new basis matrix is

$$\mathbf{B} = \begin{bmatrix} 2 & 0 \\ 3 & 1 \end{bmatrix}.$$

To get $\mathbf{B}^{-1}$, we first form the η-vector

$$\eta = \frac{1}{2}\begin{bmatrix} 1 \\ -3 \end{bmatrix}.$$

Then

$$\mathbf{B}^{-1} = \begin{bmatrix} \frac{1}{2} & 0 \\ -\frac{3}{2} & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & 0 \\ -\frac{3}{2} & 1 \end{bmatrix},$$

and

$$\mathbf{C_B B^{-1}} = [5, 0] \begin{bmatrix} \frac{1}{2} & 0 \\ -\frac{3}{2} & 1 \end{bmatrix} = [\ \frac{5}{2}, 0] \tag{2.12}$$

and

$$\mathbf{C_B B^{-1} A - C} = [\frac{5}{2}, 0] \begin{bmatrix} 1 & 2 \\ 4 & 3 \end{bmatrix} - [\,4, 5] = [-\frac{3}{2}, 0] \tag{2.13}$$

also

$$\mathbf{B^{-1}A} = \begin{bmatrix} \frac{1}{2} & 0 \\ -\frac{3}{2} & 1 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 4 & 3 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & 1 \\ \frac{5}{2} & 3 \end{bmatrix}$$

$$\mathbf{B^{-1}b} = \begin{bmatrix} \frac{1}{2} & 0 \\ -\frac{3}{2} & 1 \end{bmatrix} \begin{bmatrix} 40 \\ 120 \end{bmatrix} = \begin{bmatrix} 20 \\ 60 \end{bmatrix}$$

$$\mathbf{C_B B^{-1} b} = [5, 0] \begin{bmatrix} 20 \\ 60 \end{bmatrix} = 100$$

since one of the coefficients calculated in (2.13) is negative, the variable with the most negative coefficient, X_1, enters the basis. It replaces X_4, the pivot is 5/2.

For the second iteration, $\mathbf{X_B} = \begin{bmatrix} X_2 \\ X_1 \end{bmatrix}$ and $\mathbf{B} = \begin{bmatrix} 2 & 1 \\ 3 & 4 \end{bmatrix}$, and $\eta = 2/5 \begin{bmatrix} -\frac{1}{2} \\ 1 \end{bmatrix} = \begin{bmatrix} -\frac{1}{5} \\ \frac{2}{5} \end{bmatrix}$,

then

$$\mathbf{B^{-1}} = \begin{bmatrix} 1 & -\frac{1}{5} \\ 0 & \frac{2}{5} \end{bmatrix} \begin{bmatrix} \frac{1}{2} & 0 \\ -\frac{3}{2} & 1 \end{bmatrix} = \begin{bmatrix} \frac{4}{5} & -\frac{1}{5} \\ -\frac{3}{5} & \frac{2}{5} \end{bmatrix}$$

$$\mathbf{C_B B^{-1}} = [5, 4]\begin{bmatrix} \frac{4}{5} & -\frac{1}{5} \\ -\frac{3}{5} & \frac{2}{5} \end{bmatrix} = [\frac{8}{5}, \frac{3}{5}] \tag{2.14}$$

and

$$\mathbf{C_B B^{-1} A - C} = [\frac{8}{5}, \frac{3}{5}]\begin{bmatrix} 1 & 2 \\ 4 & 3 \end{bmatrix} - [4, 5] = [0, 0] \tag{2.15}$$

also

$$\mathbf{B^{-1} A} = \begin{bmatrix} \frac{4}{5} & -\frac{1}{5} \\ -\frac{3}{5} & \frac{2}{5} \end{bmatrix}\begin{bmatrix} 1 & 2 \\ 4 & 3 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$\mathbf{B^{-1} b} = \begin{bmatrix} \frac{4}{5} & -\frac{1}{5} \\ -\frac{3}{5} & \frac{2}{5} \end{bmatrix}\begin{bmatrix} 40 \\ 120 \end{bmatrix} = \begin{bmatrix} 8 \\ 24 \end{bmatrix}$$

$$\mathbf{C_B B^{-1} b} = [5, 4]\begin{bmatrix} 8 \\ 24 \end{bmatrix} = 136$$

since all of the Z-row coefficients in (2.15) are nonnegative, iterations terminate and the optimal solution is obtained.

2.3 Sensitivity Analysis:

"Sensitivity analysis" is also called as "postoptimality analysis" [Lock74]. Most of the coefficients which appear in an linear programming (LP) problem are not known exactly, and in practice are usually best estimates of the value that the coefficient should be [Murtagh81]. The sensitivity analysis is important to decision makers, since it gives the range of variation over the product which the contribution margin can vary without causing a change in the optimal value.

The sensitivity analysis in the farm planning problem consists of (1) changes in the coefficients (C_j) in the objective function, (2) changes in the right-hand-side values (b_i) in the resource constraint inequalities, and (3) changes in the input-output coefficients in (2.1) [Murtagh81]. This thesis only investigates the changes in the coefficients (C_j) in the objective function, since coefficients (C_j) in the objective function represent input costs and the output prices that a farm production involves and changes in these coefficients occur most frequently. Farmers also mostly concern the changes in C_j while remaining their optimal returns unchanged. The sensitivity analysis involving changes in resource constraints and input-output coefficients are much more complicated.

According to Murtagh [Murtagh81], the changes in the coefficients (C_j) affect the "sensitivity" of production in two ways: through nonbasic variables and through basic variables.

(1) Nonbasic Variables:

The change in the coefficient (C_j) of the nonbasic variable affects the reduced cost of that variable only. To perform sensitivity analysis, an arbitrary numerical quantity δ is added to C_j to see how far δ can vary before a change of basis is necessary. That is, the range over which can vary and the current solution remains optimal is given by:

$$\overline{C_j} = C_j + \delta.$$

Let d_j denotes the jth element of the reduced-cost vector,

$$d_j = Z_j - C_j,$$

then

$$\overline{d_i} = Z_j - \overline{C_j}$$
$$= Z_j - (C_j + \delta)$$
$$= d_j - \delta.$$

Where $\overline{d_i}$ is the reduced cost at the current optimum. For a nonbasic variable, the range δ is

$$-\infty < \delta \le \overline{d_i}.$$

The change beyond these limits will make the original solution nonoptimal, since the reduced cost of a nonbasic variable becomes negative.

(2) Basic Variables

The change in the coefficient of the basic variable affects the reduced cost of the nonbasic variables. For a basic variable, the range δ is

$$\max_{i|\alpha_{ij}>0}\{\frac{d_i}{-\alpha_{ij}}\} \le \delta \le \min_{i|\alpha_{ij}<0}\{\frac{d_i}{-\alpha_{ij}}\}$$

where $\alpha_{ij} = (B^{-1}a_j)_i$. If there is no $\alpha_{ij} < 0$, then $\delta < \infty$, and if there is no $\alpha_{ij} > 0$, then $\delta > -\infty$.

CHAPTER III

DESIGN AND IMPLEMENTATION OF THE FARM PLANNING MODEL SYSTEM

3.1 The Components of the Farm Planning Model System

The farm planning model system includes four parts: farm planning datasheets. farm planning model, farm planning solver and farm planning sensitivity analysis (see Figure 3.3). The farm planning model system also contains a menu bar for file handling and an on-line help menu. The first part is farm planning data sheets. It has 9 data sheets for alternative crop and livestock production activities. The information for these data sheets is from the individual enterprise budgets of the corresponding production activities. Alternative crops have five data sheets (with example data displayed in Figure 4.2 - 4.6): Native Pasture Data Sheet, Wheat for Grain Only Data Sheet, Wheat for Forage and Grain Data Sheet, Graze Out Data Sheet and Oats Data Sheet. Alternative livestock activities have four data sheets (with example data displayed in Figure 4.7 - 4.10): Cow-Calf Data Sheet, Stocker Steers on Winter Wheat Pasture Data Sheet, Stocker Steers on GrazeOut Wheat Pasture Data Sheet and Slaughter Steers Data Sheet. Another data sheet about the farm's available resources and their prices is called Farm Information Data Sheet (with example data displayed in Figure 4.1).

The second part is a farm planning model that generates the objective function and the constraint matrix for the linear programming of the farm planning problem (with example data displayed in Figure 4.11). The objective function is represented by the row "optimal". The **b** in (2.5) is represented by the column RHS. The rest of the matrix in Figure 4.11 correspond to **A** in (2.5).

The third part is the farm planning solver which solves the farm planning model and returns the optimal solution back to the same constraint matrix of Figure 4.11 in the second part. This optimal solution includes the optimal value of the objective function, the optimal amount of production activities and resource allocation, which the farmer should use and produce to maximize his/her profit.

The final part of the system is the sensitivity analysis. This part gives the range of variation of these coefficients for which the optimal solution remains optimal. These coefficients in this study include the coefficients of objective function (prices of products and costs of inputs).

3.2 The System Design of the Farm Planning Model System

The lay-out of the whole farm planning model system is shown in Figure 3.1. Figure 3.2 describes the control flow of the farm planning model system or the relationship among the four parts of the farm planning model system. The first part provides all the necessary data sheets that are required to generate the objective function and the constraint matrix in part two. Part three solves the farm planning model using the revised simplex method. The final part is the sensitivity analysis when the optimal solution is found in the third part. Figure 3.3 shows the initial screen of the farm planning model system. The command buttons at the top of the screen correspond to the different parts of this system.

3.3 Key Algorithm

a. Global variables

The whole system has 10 data sheets. The 11 arrays of global variables are declared. There is one array for each of the ten data sheet, and there is an additional array called Mtxarray(), that holds data for farm planning model (i.e. objective function and constraint matrix). The global arrays are listed below:

```
Global Mtxarray() as double          /* it holds data for farm planning model */
Global wheatforage() as double       /* it holds data for wheatforage data sheet */
Global grazeout() as double          /* it holds data for grain grazeout data sheet */
Global natpas() as double            /* it holds data for native pasture data sheet */
Global oats() as double              /* it holds data for oats data sheet */
Global wheatgrain() as double        /* it holds data for wheat for grain only data  sheet */
Global farminfo() as double          /* it holds data for farm information data sheet */
Global cow() as double               /* it holds data for cow-calf data sheet */
Global stksteer() as double          /* it holds data for stocker steers data sheet */
Global stkgrazeout() as double       /* it holds data for stocker steer grazeout data sheet */
Global ssteer() as double            /* it holds data for slaughter steer data sheet */
```

b. Farm planning model construction

The farm planning model is to link the above-mentioned 10 data sheets that are represented by forms of tables. In the complete farm planning model, column RHS represents the resource endowments and the rest of the columns represent either a production activity or a production rule. For example, column 4 in the farm planning model represents the resource requirements for production activity cow-calf, which is the information from data sheet of cow-calf. A production rule is either usage must be less than purchase or sell must be less than production. Therefore all columns together match the linear programming in (2.1).

c. Revised Simplex Method

1. Find the column with the smallest c_j.

```
Min ← c(1,1)                  /*c(1, i) are the objective coefficients*/
k ← 1                         /* k is the column number, which is initialized with 1 */
for i ← 1 to n                /* n alternatives, i.e. column */
    if Min > c(1,i) then
        Min ←c(1,i)
        k ← i                 /*the column with the smallest c_i */
    endif
next i
```

2. Find the row with the smallest R_i. (R_i= RHS_i / a_{ik})

```
Min ← B_b (1,1) / A (1,k)     /*B_b (j, 1) is the array for the RHS value*/
                              /* which is assigned by the Mtxarray(j,0),*/
                              /* 1≤ j ≤ m.  A(i, j) are assigned  by  the*/
                              /* Mtxarray(i, j), 1≤ i ≤ m, 1≤ j ≤ n */
r ← 1                         /* r is the row number, which is initialized with 1 */
for j ← 1 to m                /* m is the number of resource constraints */
    if Min > B_b(j, 1) / A(j, k) then
        Min ← B_b(j, 1) / A(j, k)
        r ← j                 /* the row with the smallest R_i */
    endif
next j
```

3. Calculate η-vector. ($a_{jk} = a_{jk}$ / a_{rk})

```
for j ← 1 to m                /* m row */
    if j ←r then              /* rth row */
        η (j, 1) ← 1 / A(r, k)
    else
        η (j, 1) ← - A(j, k) / A(r, k)
    endif
next j
```

4. Calculate the B^{-1}.

```
/* B is the submatrix of A that is associated with basic variables */
call matrixmultiply (m, m, B_0(), m, B_1(), B_inv() )
/* This function multiplies two matrices.  m stands for the */
/* number of rows of the matrix. B_0() is an m × m matrix,  */
/* which is initialized with an identity matrix, and its rth column's */
/* value are assigned by η-vector. */
/* B_1() is an m × m identity matrix.  B_inv() is the inverse matrix of B, */
/* which is an m × m matrix. */
```

```
sub matrixmultiply (byval m as integer, byval n as integer, A() as double,
                    byval l as integer, B() as double, C() as double)
for i ← 1 to m
    for j ← 1 to l
        C(i, j) ← 0
        for k ← 1 to n
            C(i, j) ← C(i, j) + A(i, k)* B(k, j)
        next k
    next j
next i
end sub
```

5. Calculate the $C_B B^{-1}$.

```
/* C_B are the objective coefficients for the basic variables */
call matrixmultiply (1, m, CB1(), m, B_inv(), CB() )
/* CB1() is the matrix that holds objective coefficients for the basic variables */
/* CB() = CB1() × B_inv() */
```

6. Calculate the $C_B B^{-1}A$ - C.

```
/* A is the input-output coefficient matrix. C is the matrix that holds */
/* objective coefficients associated with nonbasic variables, */
/* and its values are assigned by Mtxarray(0, i), 1≤ i ≤ n */
call matrixmultiply (1, m, CB(), n, A(), CBA() )
/* CBA = CB() × A() */
    for j ← 1 to n          /*n columns */
        C_1(1, j) ← CBA(1, j) - C(1,j)
    next j
```

7. Calculate the $B^{-1}A$.

```
call matrixmultiply (m, m, B_inv(), n, A(), A1() )
/* A1() = B_inv() × A() */
```

8. Calculate the $B^{-1}b$.

```
/*b is the RHS which is assigned by Mtxarray (j,0), 1≤ j ≤ m */
call matrixmultiply (m, m, B_inv(), 1, b(), B_b() )
/* B_b() = B_inv() × b() */
```

9. Calculate $C_B B^{-1}b$.

```
CBb ← 0
for i ← 1 to m
    CBb ← CB1(1, i ) * B_b(i, 1) + CBb
next i
```

10. Assign $B_{inv}()$ to $B_1()$.

```
/*for iteration */
for i ← 1 to m
     for j ← 1 to m
         B1(i, j) ←Binv( i, j)
     next j
next i
```

11. Sensitivity analysis

(a) for nonbasic variables

min ← $C_1(1, j)$ /* $C_1(1, j) \leftarrow CBA(1, j) - C(1,j)$, $1 \le j \le n$ */
max ← 1E + 30

(b) for basic variables

min ← $-C_1(1, j) / A1(p, j)$ /*p is the row number for the basic variable, $1 \le j \le n$ */
max ← $C_1(1, j) / A1(p, j)$

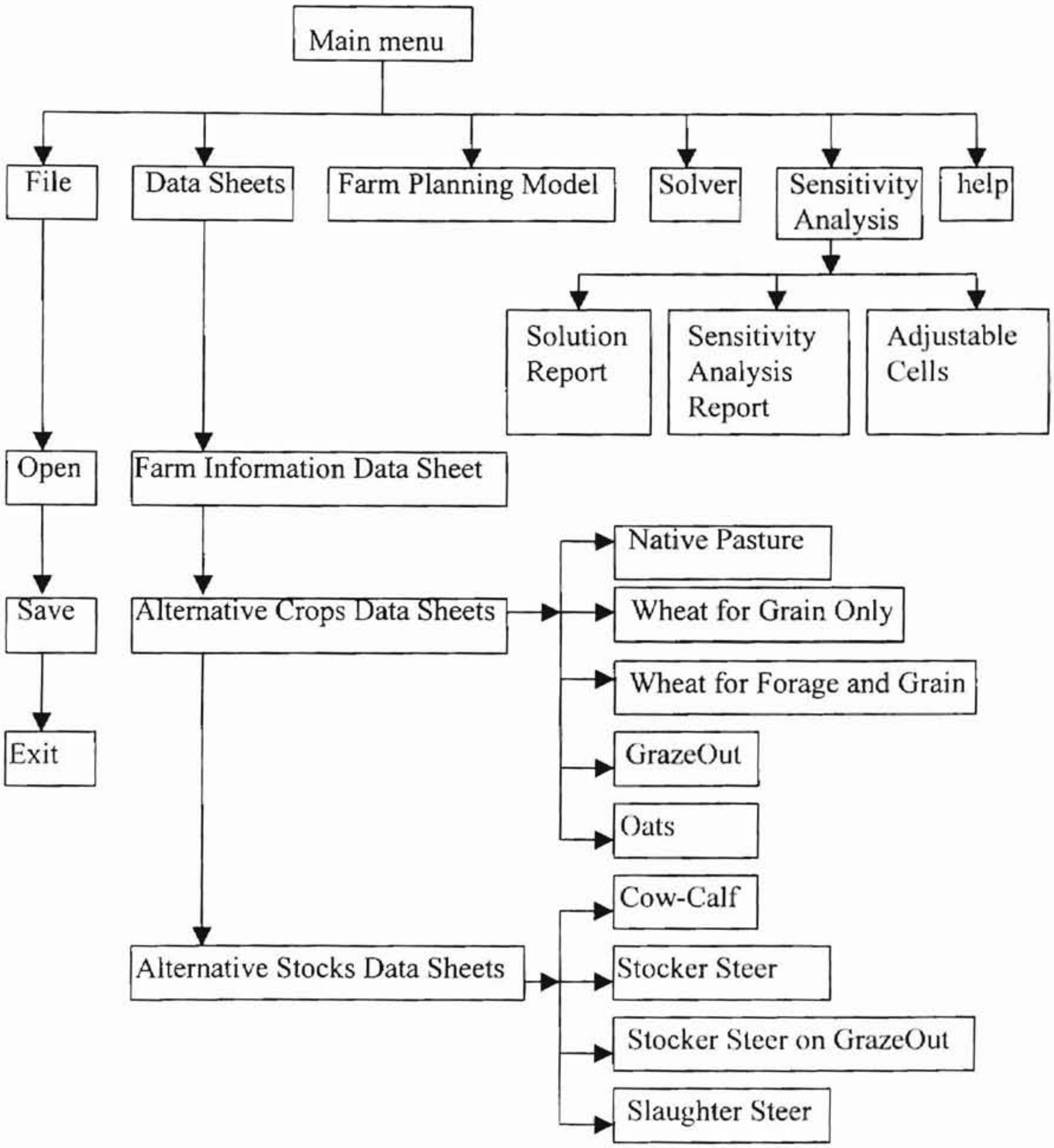


Figure 3.1 Menu Organization (System View)

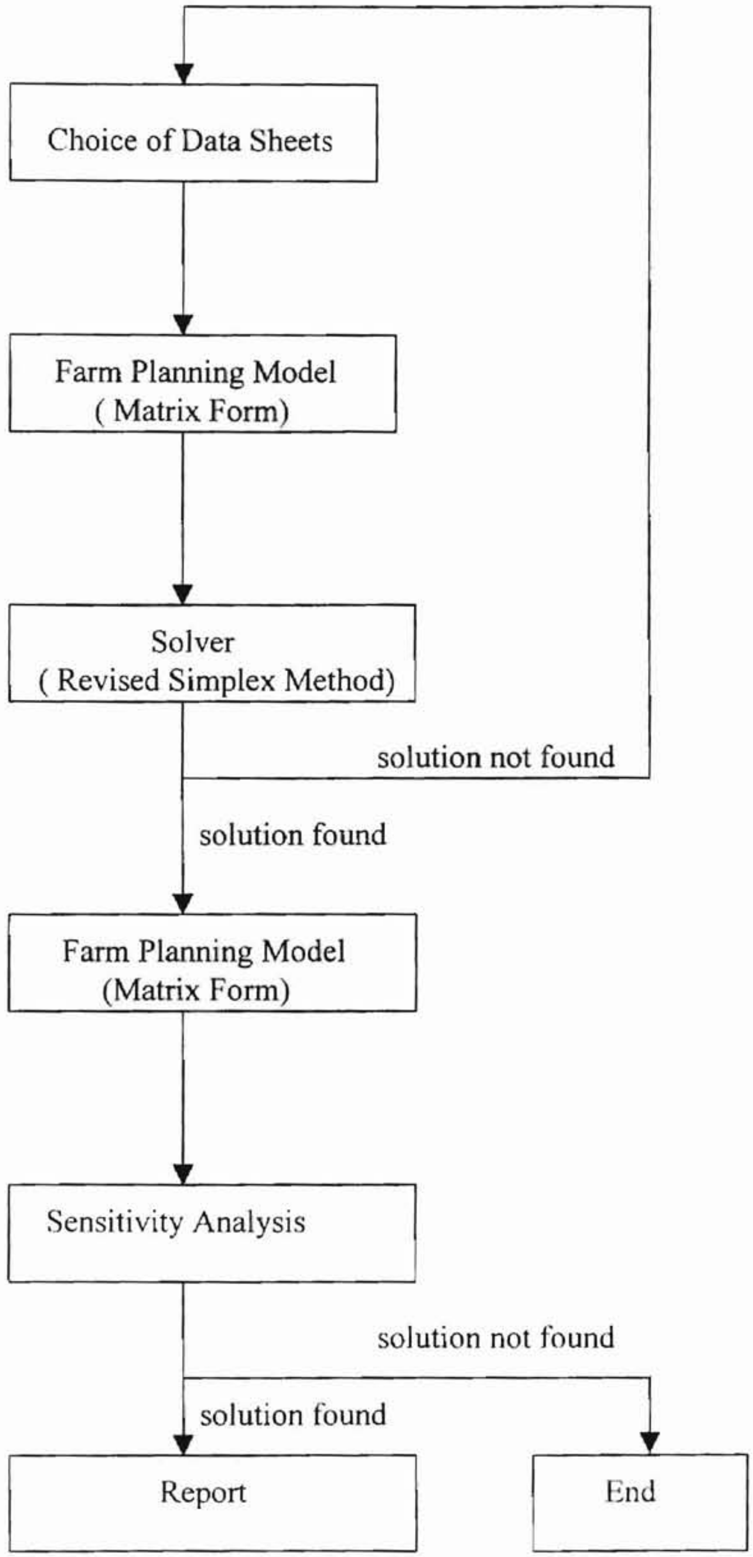


Figure 3.2 The Control Flow of the Farm Planning Model System

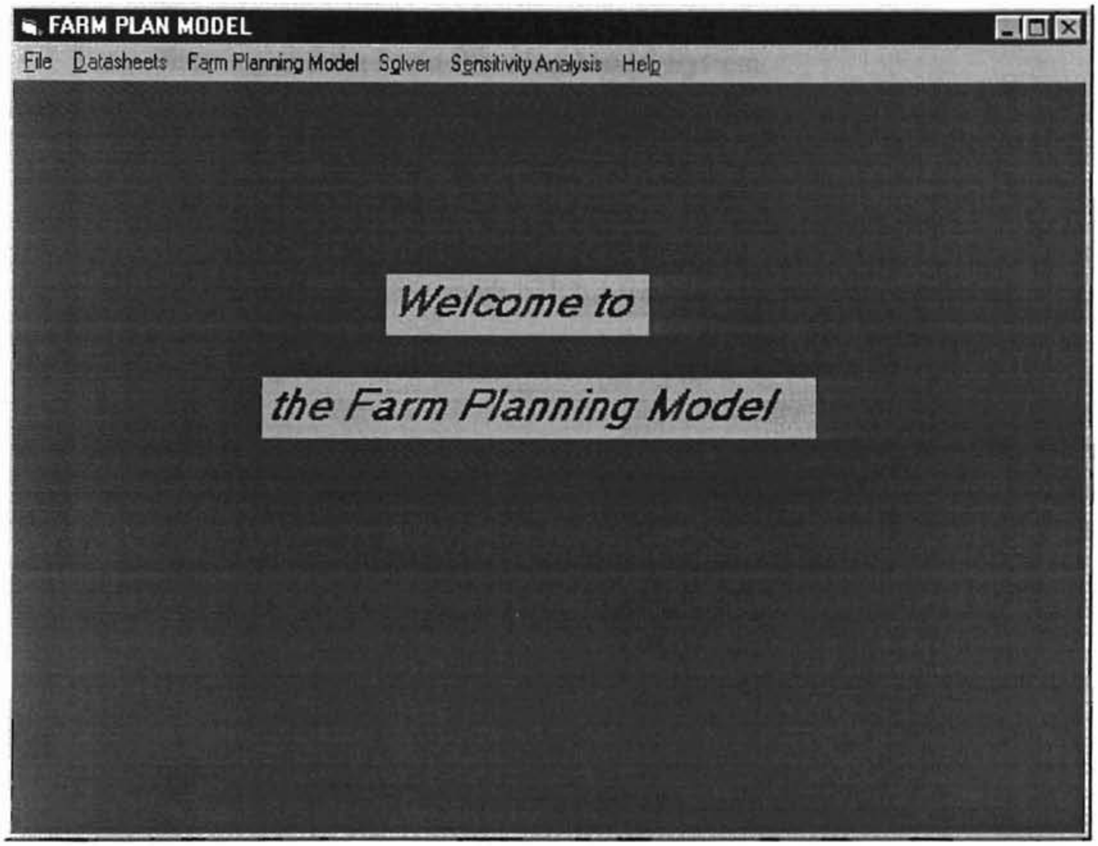


Figure 3.3 The Main Menu of the Farm Planning Model System

CHAPTER IV

AN APPLICATION OF THE FARM PLANNING MODEL SYSTEM

4.1 Farm Planning and the Farm Planning Model System

Farm Planning is to determine optimal allocation of a farm's limited resources such as land, labor and capital among alternative crop and livestock enterprises. It helps farmers to decide what and how much will be produced to make the optimal returns from the resources they have or have access. The farm planning model system can be used to help farmers in conducting such kinds of decision-making – to maximize returns from their production activities given the amount of resources available to them. In order to do so, relevant information is needed, such as the prices of farm production outputs, the amount of resources a farm has or has access, the prices of these resources and farm production inputs and so on.

4.2 The OSU Enterprise Budgets

Enterprise budgets provide such kind of information for different number of production activities. Enterprise budgets have been developed by OSU agricultural economist in four principal types of budgets used in farm decision making [Doye88a]. These four types of budgets are: whole farm, cash flow, enterprise and partial budgets. Enterprise budgets project the costs and returns for an activity or activities - raising livestock, producing grain, growing vegetable and so on - for some period, generally one year. OSU enterprise budgets are made available to producers through County Extension offices and area agricultural economics specialists.

The enterprise budget incorporates information about a specific resource, management practices and technology used in the production process. For instance, separate enterprise budgets are specified for different calving seasons and feeding systems in cow-calf operations[Doye88]. For the details of the OSU Enterprise Budgets, please refer to Doye[Doye881, Doye88b].

4.3 An Example of the Farm Planning Model

The following example is a typical farm planning problem. This farm planning problem has two types of production alternatives: alternative stocks and alternative crops. These two production alternatives include nine production activities: Native Pasture, Wheat for Grain Only, Wheat for Forage and Grain, Grain GrazeOut , Oats, Cow-Calf, Stocker Steers, Stocker Steers on GrazeOut, and Slaughter Steers. Each production activity provides with information on how much labor, land, capital, fertilizer, machinery, insurance, insecticide, seed etc. are needed to produce one unit of this product. Figure 4.1 provides the information about a farm's total available resources, such as land, labor, capital and their prices. The data sheets in figures 4.2 through 4.10 provide enterprise budget information for the above-mentioned nine production activities.

Figures 4.11 and 4.12 provide the solution of the example farm planning problem. The solution of the farm planning problem is returned in two forms. Figure 4.11 provide the solution in the matrix form. The first row of Figure 4.11 provides the optimal production activities and the first column of Figure 4.11 are the resources that are used to attain the above optimal. The maximum amount of profit is $77164.30. Figure 4.12 provides the solution in plain text form, which is easily understood by farmers. Figure 4.13 is the result of the sensitivity analysis. Figure 4.14 provides the sensitivity analysis report in plain text form that is easily understood by farmers. Tables 4.1 and 4.2 summarize the solution of this farm planning problem. Table 4.3 is the summary of the sensitivity analysis.

Table 4.1 Optimal Production Activities for the Example Farm Planning Problem

Production Activities:	Units
Cow-Calf	24.5 heads
Stocker Steers	398.9 heads
Stocker Steers on Graze Out	0
Slaughter Steers	0
Wheat for Grain Only	573.7 bu.
Wheat for Grain and Forage	226.3 bu.
Native Pasture	600 aums
Oats	0
Grain Graze Out	0
Hire Labor (Jan-Feb-Mar)	322.7 hrs.
Hire Labor (Apr-May-Jun)	0
Hire labor (Jul-Aug-Sep)	0
Hire labor (Oct-Nov-Dec)	860.8 hrs.
Borrowed Capital	$90,000.00
Sell Steer Calves (4-5)	0
Sell Heifer Calves (4-5)	31 cwt. (7.35 heads)
Sell Commercial Cows	21.4 cwt. (2.45 heads)
Sell Aged Bulls	3.3 cwt. (0.24 heads)
Buy Steer Calves (4-5)	1,692.2 cwt. (387.23 heads)
Sell Heifer Calves (6-7)	3 cwt. (0.50 heads)
Sell Steer Calves (6-7)	2,708.7 cwt. (398.92 heads)
Sell Steer Calves (7-8)	0
Buy Steer Calves (7-8)	0
Sell Slaughter Steer	0
Sell Wheat	2,5842.3 bu.
Sell Oats	0
Pasture Transfer from 1st Season to 2nd Season	0
Pasture Transfer from 2nd Season to 3rd Season	132.9 aums
Pasture Transfer from 3rd Season to 4th Season	220.3 aums
Pasture Transfer from 4th Season to 1st Season	187.9 aums

Table 4.2 Resource Allocations for the Example Farm Planning Problem

Resources	Required	Available
Land for Pasture	600 acres	600 acres
Land for Crop	800 acres	800 acres
Labor (Jan-Feb-Mar)	450 hrs.	450 hrs.
Labor (Apr-May-Jun)	276 hrs.	450 hrs.
Labor (Jul-Aug-Sep)	450 hrs.	450 hrs.
Labor (Oct-Nov-Dec)	450 hrs.	450 hrs.
Own Capital	\$9,990.00	\$10,000.00
Borrowed Capital	\$90,000.00	\$90,000.00
Pasture balance in 1st Season	0	0
Pasture balance in 2nd Season	0	0
Pasture balance in 3rd Season	0	0
Pasture balance in 4th Season	0	0
Balance for Steers 437	0	0
Balance for Heifer 422	0	0
Balance for Commercial Cows	0	0
Balance for Aged Bulls	0	0
Balance for Heifer 605	0	0
Balance for Steers 665	0	0
Balance for Steers 1065	0	0
Balance for Wheat	0	0
Balance for Oats	0	0
Balance for Steers 764	0	0

Table 4.3 Sensitivity Analysis for the Example Farm Planning Problem

Production Activities:	Reduced Cost	Range of Variation
Cow-Calf	0	8.74 ~ 81.98
Stocker Steers	0	92.11 ~ 12.98
Stocker Steers on Graze Out	-27.3	27.3 ~ 1E + 30
Slaughter Steers	-73.86	73.86 ~ 1E + 30
Wheat for Grain Only	0	150.19 ~3.27
Wheat for Grain and Forage	0	3.27 ~ 68.37
Native Pasture	0	1E + 30 ~ 1E + 30
Oats	-37.81	37.81 ~ 1E + 30
Grain Graze Out	-79.63	79.63 ~ 1E + 30
Hire Labor (Jan-Feb-Mar)	0	2.29 ~ 23.76
Hire Labor (Apr-May-Jun)	-7.23	7.23 ~ 1E + 30
Hire labor (Jul-Aug-Sep)	-2.75	2.75 ~ 1E + 30
Hire labor (Oct-Nov-Dec)	0	10.17 ~ 22.84
Borrowed Capital	0	200000 ~ 1E + 30
Sell Steer Calves (4-5)	0	0 ~ 1E + 30
Sell Heifer Calves (4-5)	0	6.9 ~ 64.75
Sell Commercial Cows	0	10.01~ 93.9
Sell Aged Bulls	0	64.33 ~ 603.67
Buy Steer Calves (4-5)	0	0 ~ 1.8
Sell Heifer Calves (6-7)	0	72.19 ~ 677.51
Sell Steer Calves (6-7)	0	13.57 ~ 1.91
Sell Steer Calves (7-8)	0	0 ~ 1E + 30
Buy Steer Calves (7-8)	0	0 ~ 3.57
Sell Slaughter Steer	0	6.32 ~ 1E + 30
Sell Wheat	0	25.03 ~ 0.55
Sell Oats	0	0.69 ~ 1E + 30
Pasture Transfer from 1st Season to 2nd Season	-4.81	4.81 ~ 1E + 30
Pasture Transfer from 2nd Season to 3rd Season	0	4.81 ~ 2.58
Pasture Transfer from 3rd Season to 4th Season	0	4.61 ~ 1.27
Pasture Transfer from 4th Season to 1stSeason	0	4.76 ~ 1.7

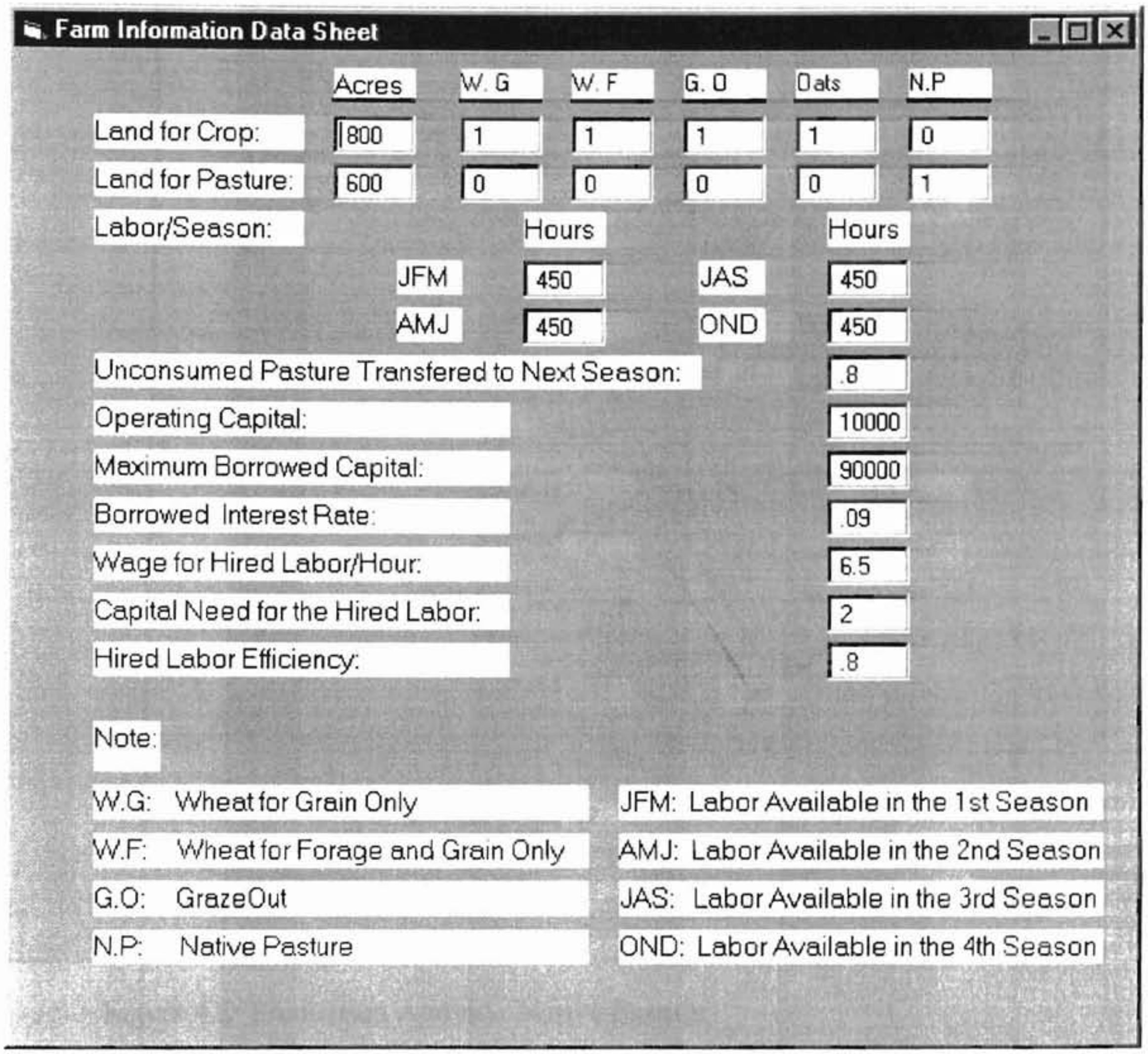


Figure 4.1 Farm Information data Sheet

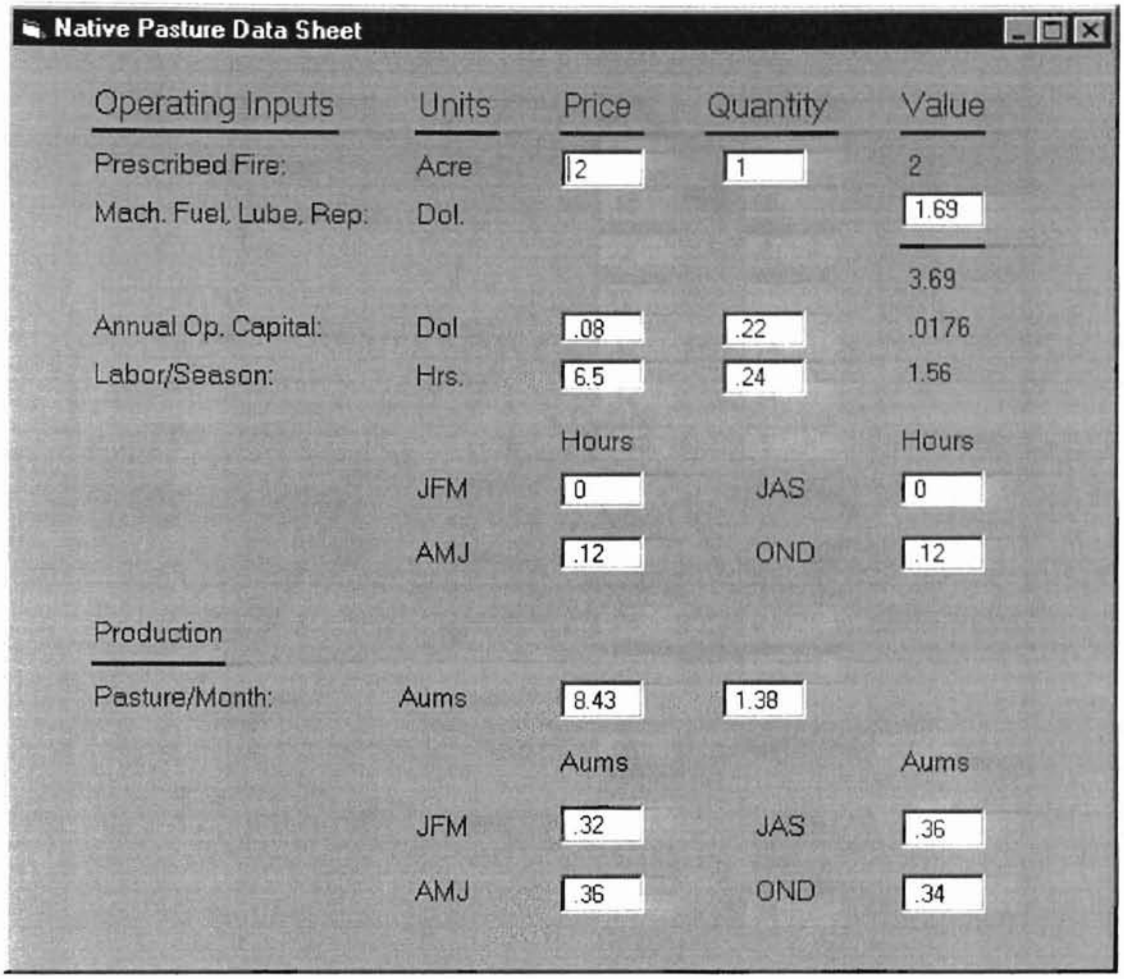
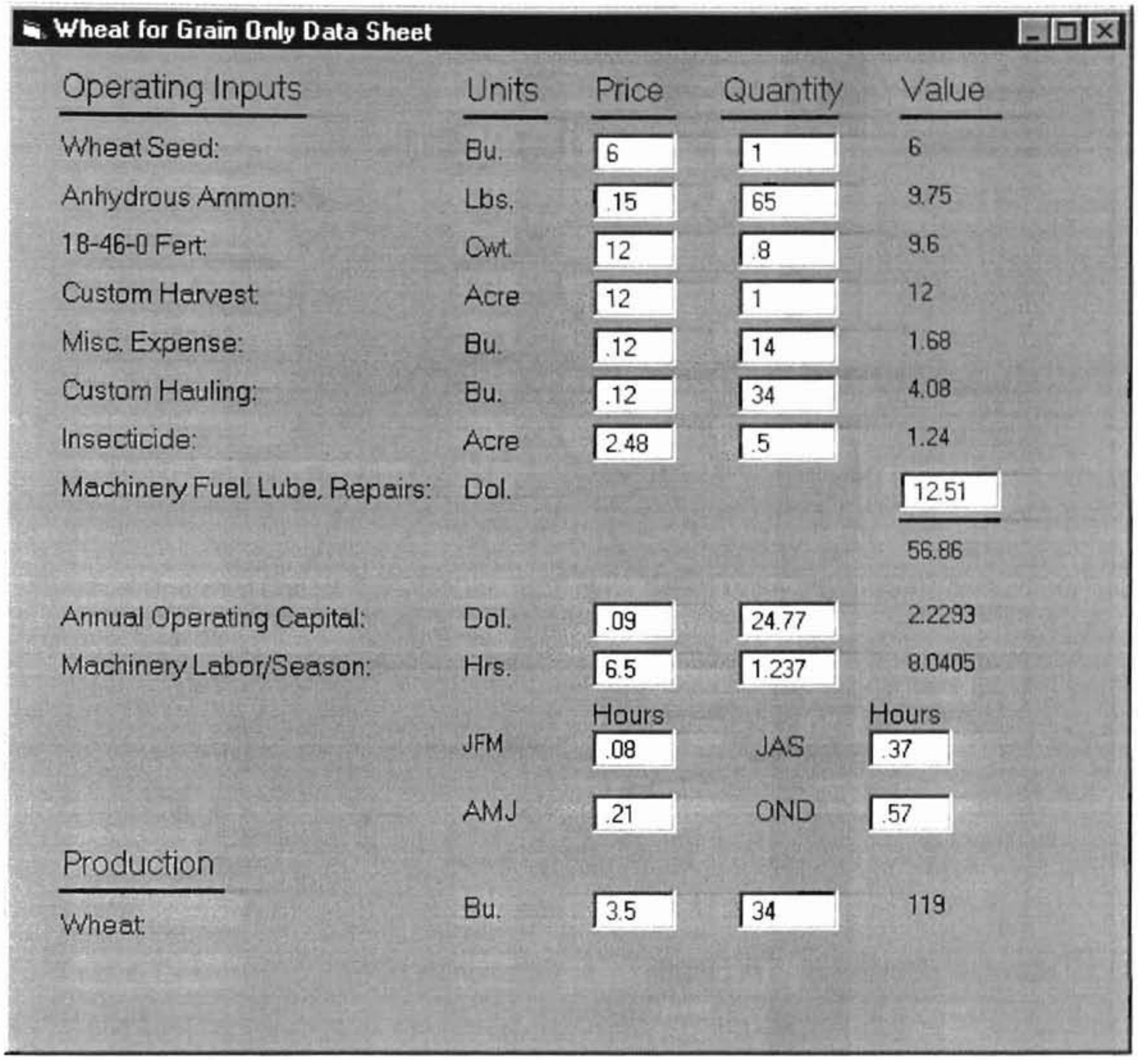


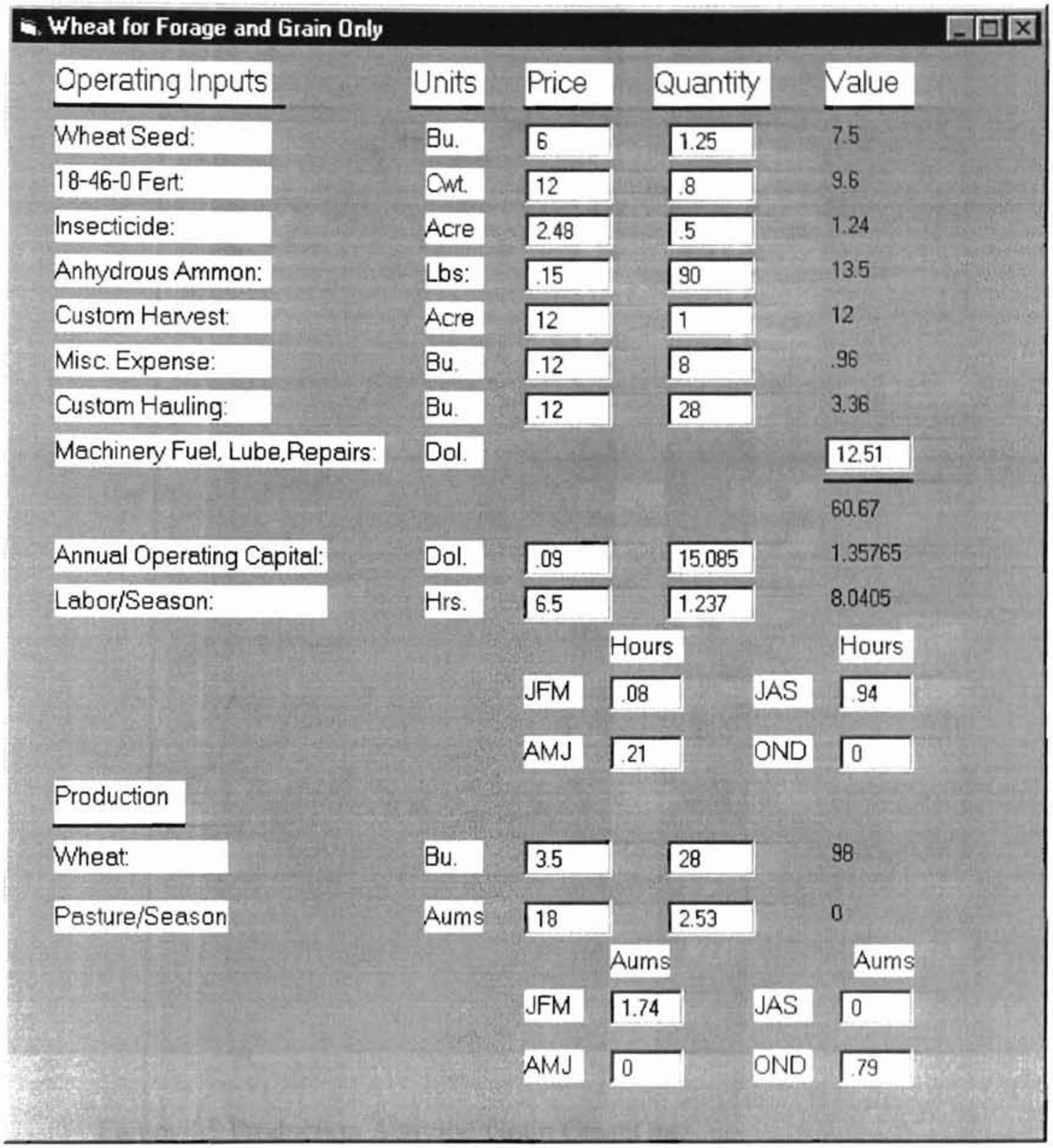
Figure 4.2 Production Activity: Native Pasture



Wheat for Grain Only Data Sheet

Operating Inputs	Units	Price	Quantity	Value
Wheat Seed:	Bu.	6	1	6
Anhydrous Ammon:	Lbs.	.15	65	9.75
18-46-0 Fert:	Cwt.	12	.8	9.6
Custom Harvest:	Acre	12	1	12
Misc. Expense:	Bu.	.12	14	1.68
Custom Hauling:	Bu.	.12	34	4.08
Insecticide:	Acre	2.48	.5	1.24
Machinery Fuel, Lube, Repairs:	Dol.			12.51
				56.86
Annual Operating Capital:	Dol.	.09	24.77	2.2293
Machinery Labor/Season:	Hrs.	6.5	1.237	8.0405
		Hours		Hours
	JFM	.08	JAS	.37
	AMJ	.21	OND	.57
Production				
Wheat:	Bu.	3.5	34	119

Figure 4.3 Production Activity: Wheat for Grain Only



Wheat for Forage and Grain Only

Operating Inputs	Units	Price	Quantity	Value
Wheat Seed:	Bu.	6	1.25	7.5
18-46-0 Fert:	Cwt.	12	.8	9.6
Insecticide:	Acre	2.48	.5	1.24
Anhydrous Ammon:	Lbs:	.15	90	13.5
Custom Harvest:	Acre	12	1	12
Misc. Expense:	Bu.	.12	8	.96
Custom Hauling:	Bu.	.12	28	3.36
Machinery Fuel, Lube,Repairs:	Dol.			12.51
				60.67
Annual Operating Capital:	Dol.	.09	15.085	1.35765
Labor/Season:	Hrs.	6.5	1.237	8.0405

	Hours		Hours
JFM	.08	JAS	.94
AMJ	.21	OND	0

Production	Units	Price	Quantity	Value
Wheat:	Bu.	3.5	28	98
Pasture/Season	Aums	18	2.53	0

	Aums		Aums
JFM	1.74	JAS	0
AMJ	0	OND	.79

Figure 4.4 Production Activity: Wheat for Grain and Forage

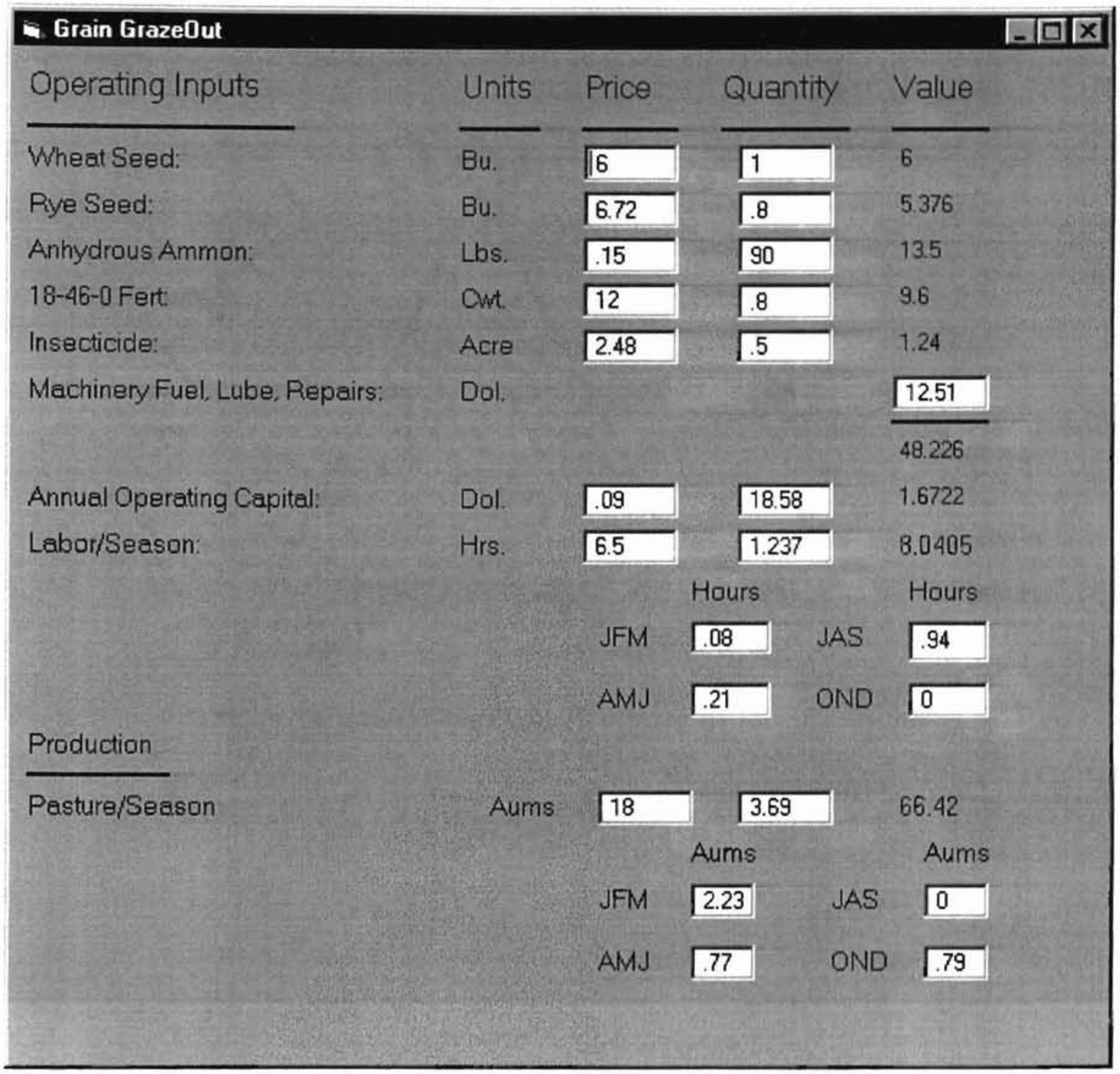


Figure 4.5 Production Activity: Grain GrazeOut

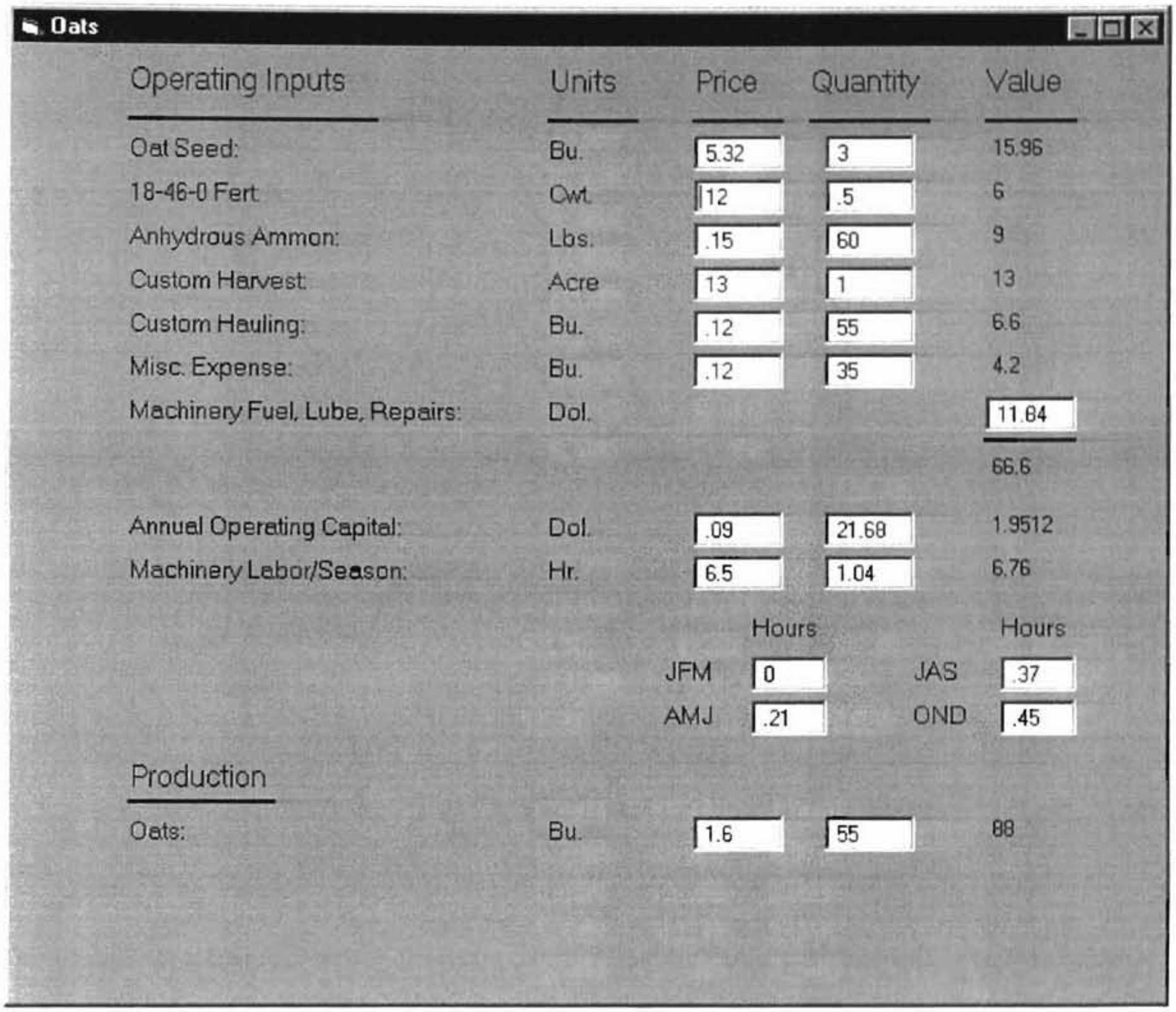


Figure 4.6 Production Activity: Oats

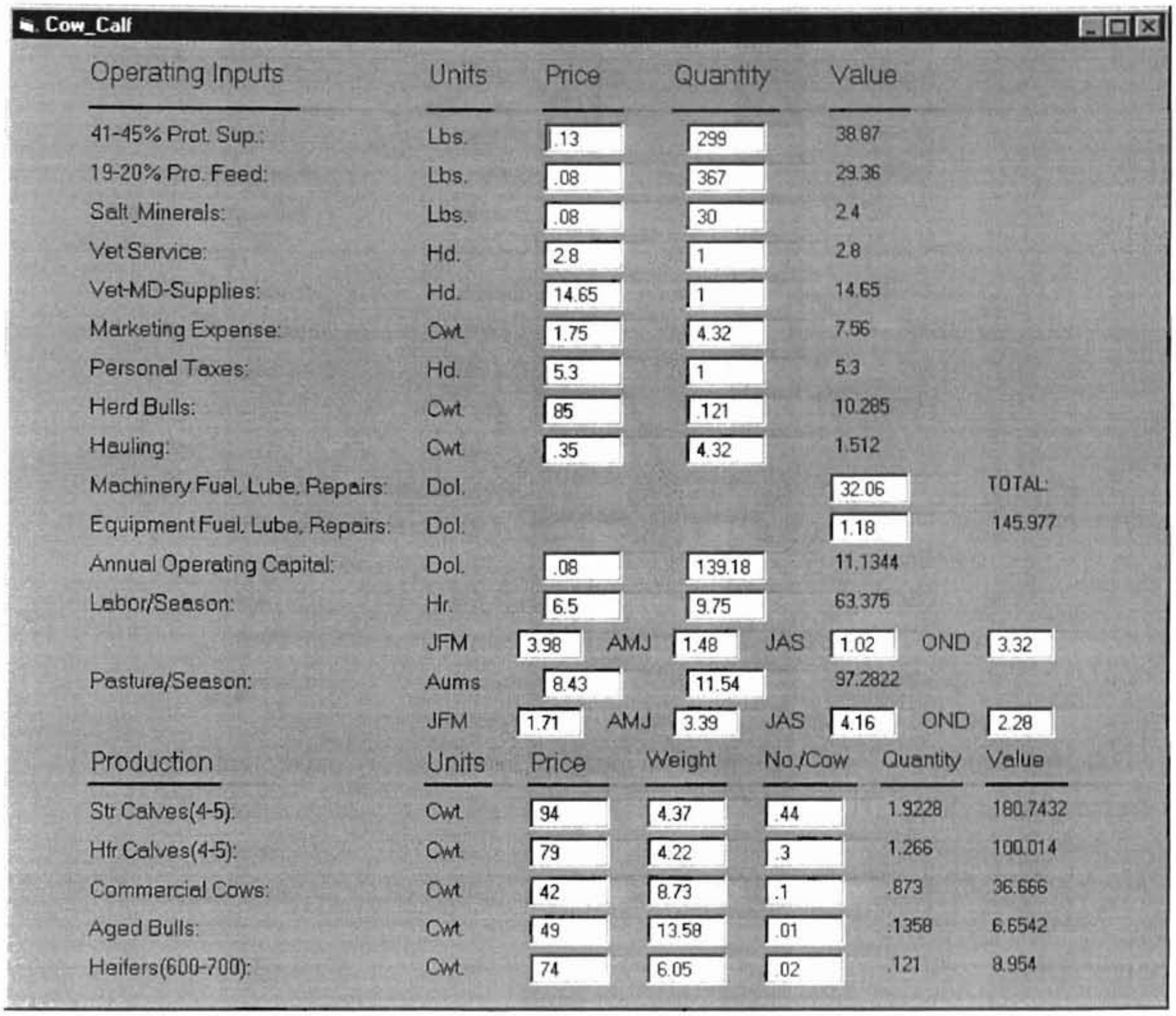


Figure 4.7 Production Activity: Cow_Calf

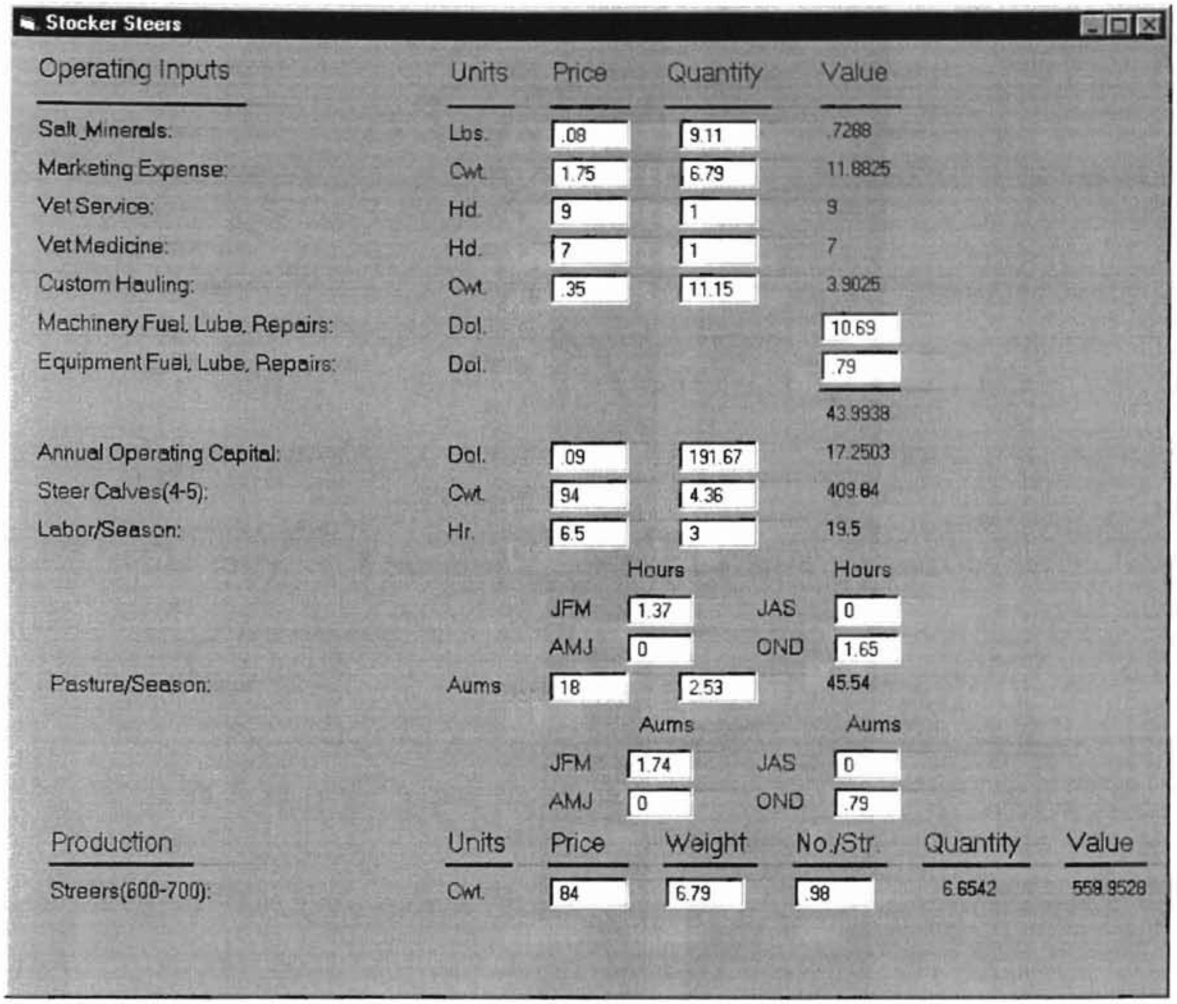


Figure 4.8 Production Activity: Stocker Steers

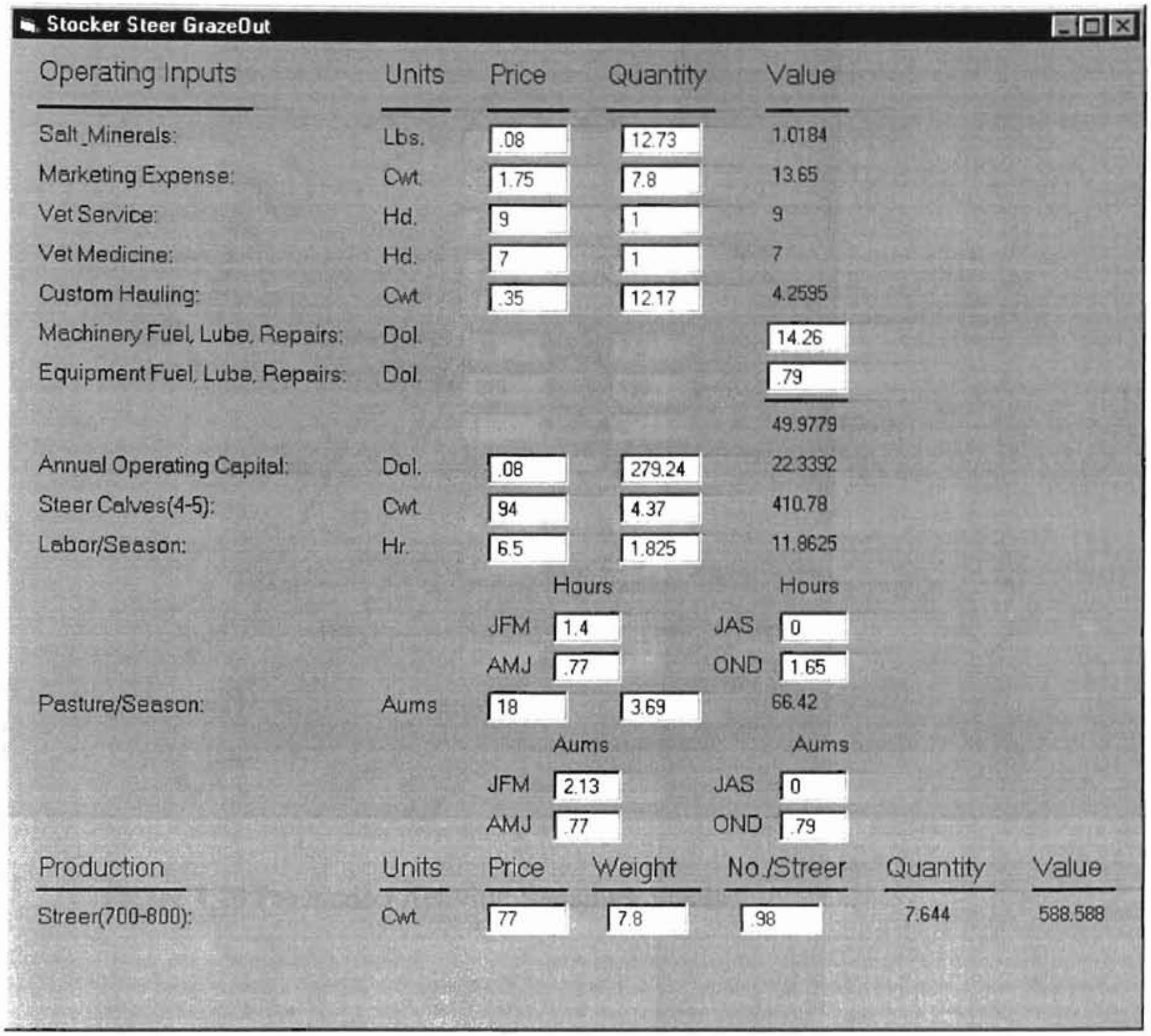


Figure 4.9 Production Activity: Stocker Steers GrazeOut

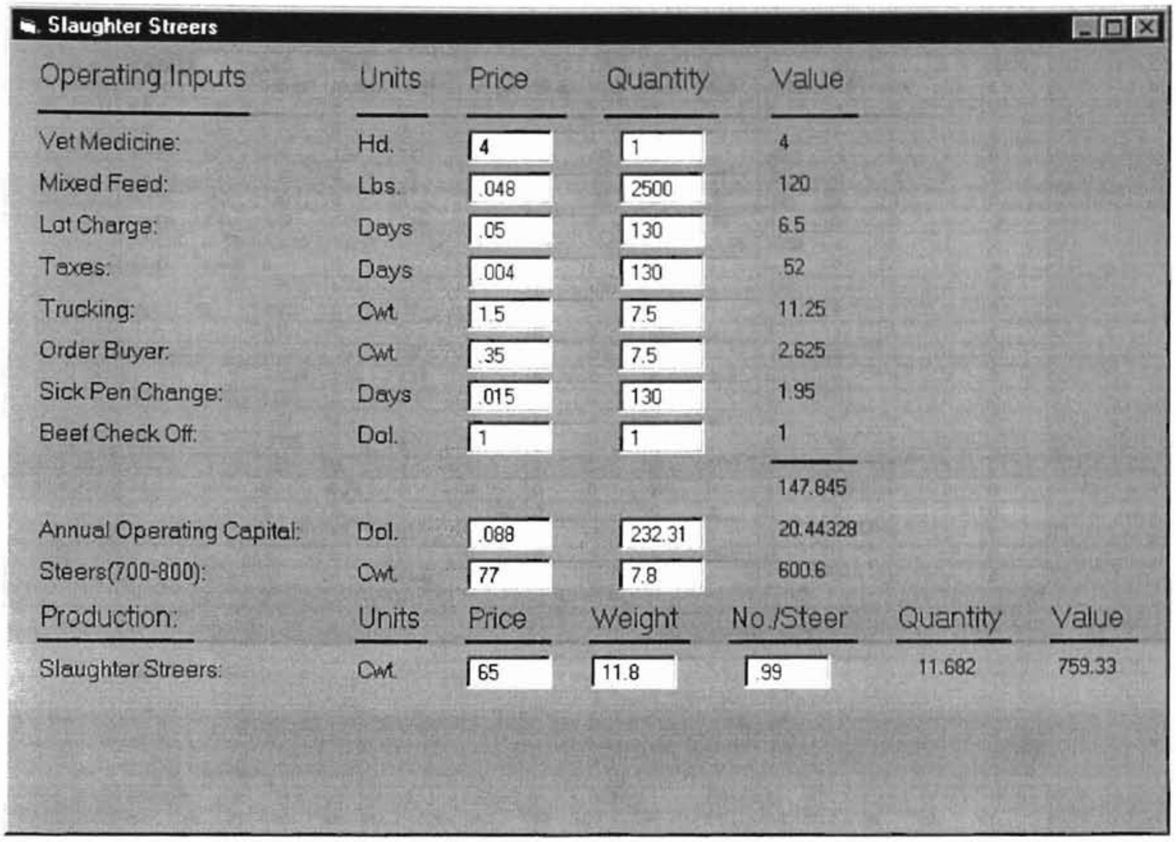


Figure 4.10 Production Activity: Slaughter Steers

The farm Planning Model

	Value	RHS	Cow	SStr	SGO	SISt	W_G	W_FG	NP	Oat	GO	HJFM	HAMJ	HJAS	HOND
			24.5	398.9	0	0	573.7	226.3	600	0	0	322.7	0	0	860.8
Optimal	77164.3	0	-145.977	-43.9938	-49.9779	-147.845	-56.86	-60.67	-3.69	-66.6	-48.226	-6.5	-6.5	-6.5	-6.5
LandPT	600	600	0	0	0	0	0	0	1	0	0	0	0	0	0
LandCP	800	800	0	0	0	0	1	1	0	1	1	0	0	0	0
LBJFM	449.84	450	3.98	1.37	1.4	0	.08	.08	0	0	.08	-.8	0	0	0
LBAMJ	276.26	450	1.48	0	.77	0	.21	.21	.12	.21	.21	0	-.8	0	0
LBJAS	449.98	450	1.02	0	0	0	.37	.94	0	.37	.94	0	0	-.8	0
LBOND	449.89	450	3.32	1.65	1.65	0	.57	0	.12	.45	0	0	0	0	-.8
Capital	9990.36	10000	139.18	191.67	279.24	232.31	24.77	15.085	.22	21.68	18.58	2	2	2	2
MaxBor	90000	90000	0	0	0	0	0	0	0	0	0	0	0	0	0
PTJFM	-.1	0	1.71	1.74	2.13	0	0	-1.74	-.32	0	-2.23	0	0	0	0
PTAMJ	-.05	0	3.39	0	.77	0	0	0	-.36	0	-.77	0	0	0	0
PTJAS	-.1	0	4.16	0	0	0	0	0	-.36	0	0	0	0	0	0
PTOND	-.13	0	2.28	.79	.79	0	0	-.79	-.34	0	-.79	0	0	0	0
St437BL	-.1	0	-1.9228	4.36	4.37	0	0	0	0	0	0	0	0	0	0
Hf422BL	-.02	0	-1.266	0	0	0	0	0	0	0	0	0	0	0	0
CmCowBL	.01	0	-.873	0	0	0	0	0	0	0	0	0	0	0	0
AgBulBL	-.03	0	-.1358	0	0	0	0	0	0	0	0	0	0	0	0
Hf605BL	.04	0	-.121	0	0	0	0	0	0	0	0	0	0	0	0
St665BL	.17	0	0	-6.79	0	0	0	0	0	0	0	0	0	0	0
St1065BL	0	0	0	0	0	-11.682	0	0	0	0	0	0	0	0	0
WhtBL	.1	0	0	0	0	0	-.34	-.28	0	0	0	0	0	0	0
OatBL	0	0	0	0	0	0	0	0	0	-.55	0	0	0	0	0
St764BL	0	0	0	0	-7.644	7.8	0	0	0	0	0	0	0	0	0

The farm Planning Model

	Borw	SIS45	SIH45	SICow	SIBul	BSt45	SIH67	SIS665	SIS764	BSt780	SIS1114	SIW	SIOat	PTF_S	PTS_T	PTT_F	PTF_F
	90000	0	31	21.4	3.3	1692.2	3	2708.7	0	.00005	0	25842.3	0	0	132.9	220.3	187.9
Optimal	-.09	.94	.79	.42	.49	-.94	.74	.84	.77	-.77	.65	3.5	1.6	0	0	0	0
LandPT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LandCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LBJFM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LBAMJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LBJAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LBOND	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capital	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MaxBor	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTJFM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-.8
PTAMJ	0	0	0	0	0	0	0	0	0	0	0	0	0	-.8	1	0	0
PTJAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-.8	1	0
PTOND	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-.8	1
St437BL	0	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0
Hf422BL	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CmCowBL	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
AgBulBL	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hf605BL	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
St665BL	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
St1065BL	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
WhtBL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
OatBL	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
St764BL	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0

Figure 4.11 The Solution of the Farm Planning Problem (in Matrix Form)

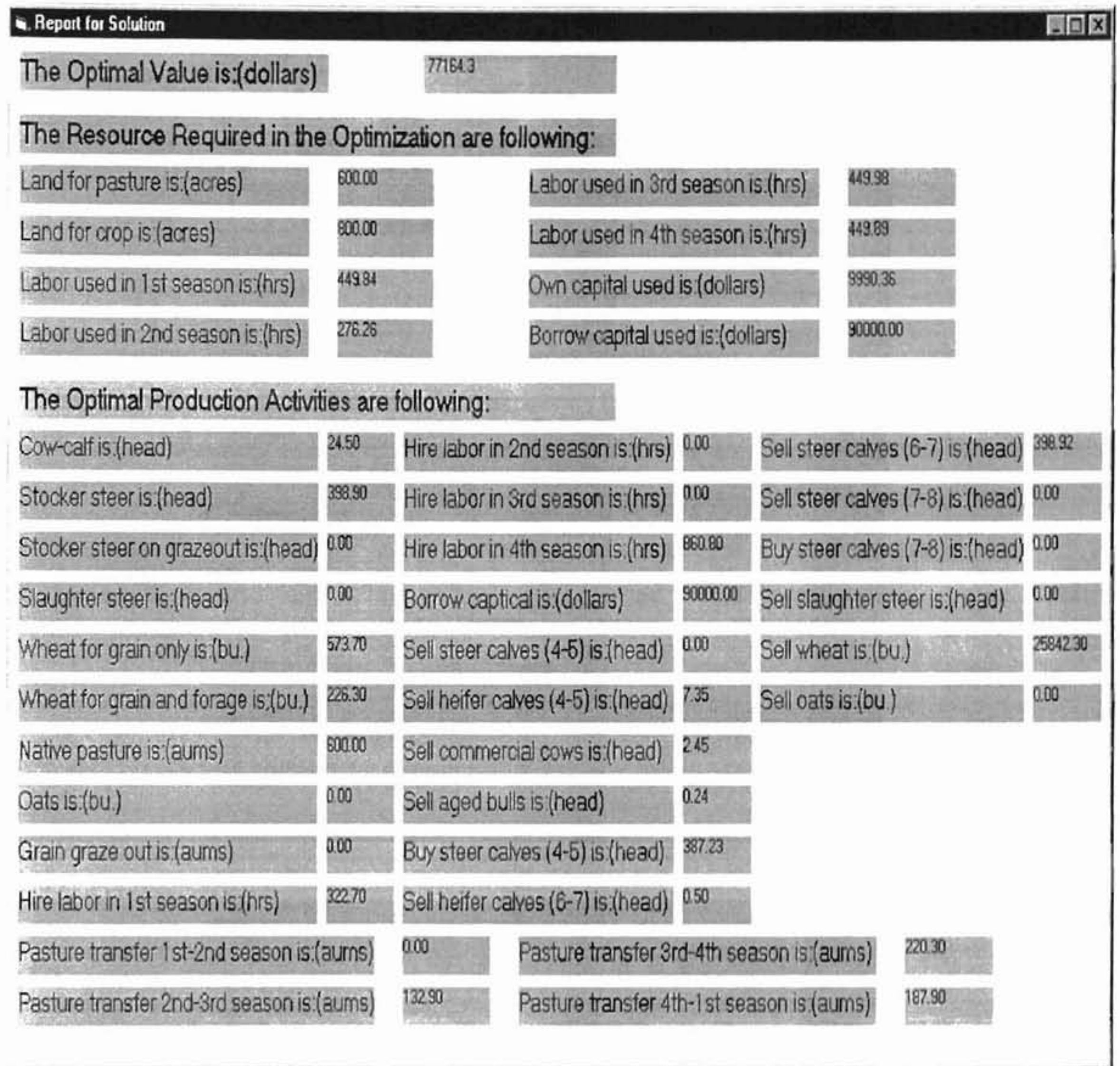


Figure 4.12 The Solution Report of the Farm Planning Problem (in Plain Text)

Sensitivity Report1

Name	cow	sstr	sgo	slstr	w_g	w_fg	np	oat	go	hjfm
Final Value	24.52	398.93	0	0	573.71	226.29	600	0	0	322.68
Reduced Cost	0	0	-27.3	-73.86	0	0	0	-37.81	-79.63	0
Objective Coefficient	-145.98	-43.99	-49.98	-147.85	-56.86	-60.67	-3.69	-66.6	-48.23	-6.5
Allowable Increase	8.74	92.11	27.3	73.86	150.19	3.27	1E+30	37.81	79.63	2.29
Allowable Decrease	81.98	12.98	1E+30	1E+30	3.27	68.37	1E+30	1E+30	1E+30	23.76

Sensitivity Report1

Name	hamj	hjas	hond	borw	sls45	slh45	slcow	slbul	bst45	slh67
Final Value	0	0	860.84	89999.99	0	31.05	21.41	3.33	1692.19	2.97
Reduced Cost	-7.23	-2.75	0	0	0	0	0	0	0	0
Objective Coefficient	-6.5	-6.5	-6.5	-.09	94	79	42	49	-94	74
Allowable Increase	7.23	2.75	10.17	200000	0	6.9	10.01	64.33	0	72.19
Allowable Decrease	1E+30	1E+30	22.84	1E+30	1E+30	64.75	93.9	603.67	1.8	677.51

Sensitivity Report1

Name	sls665	sls764	bst780	sls1114	slw	sloat	ptf_s	pts_t	ptt_f	ptf_f
Final Value	2708.75	0	0	0	25842.26	0	0	132.86	220.27	187.92
Reduced Cost	0	0	0	0	0	0	-4.81	0	0	0
Objective Coefficient	84	77	-77	65	3.5	1.6	0	0	0	0
Allowable Increase	13.57	0	0	6.32	25.03	.69	4.81	4.81	4.61	4.76
Allowable Decrease	1.91	1E+30	3.57	1E+30	.55	1E+30	1E+30	2.58	1.27	1.7

Figure 4.13 The Solution of the Sensitivity Analysis

Sensitivity Analysis Report

The Following Gives the Ranges of Objective Coefficients that the Optimal Solution Remains

Optimal Value: 77164.3

	Allowable Increase	Allowable Decrease
Cow-Calf:	8.74	81.98
Stocker Steers:	92.11	12.98
Stocker Steers on Graze Out:	27.3	1E+30
Slaughter Steers:	73.86	1E+30
Wheat for Grain Only:	150.19	3.27
Wheat for Grain and Forage:	3.27	68.37
Native Pasture:	1E+30	1E+30
Oats:	37.81	1E+30
Grain Graze Out:	79.63	1E+30
Hire Labor (JFM):	2.29	23.76
Hire Labor (AMJ):	7.23	1E+30
Hire Labor (JAS):	2.75	1E+30
Hire Labor (OND):	10.17	22.84
Borrowed Capital:	200000	1E+30
Sell Steer Calves (4-5):	0	1E+30

	Allowable Increase	Allowable Decrease
Sell Heifer Calves (4-5):	6.9	64.75
Sell Commercial Cows:	10.01	93.9
Sell Aged Bulls:	64.33	603.67
Buy Steer Calves (4-5):	0	1.8
Sell Heifer Calves (6-7):	72.19	677.51
Sell Steer Calves (6-7):	13.57	1.91
Sell Steer Calves (7-8):	0	1E+30
Buy Steer Calves (7-8):	0	3.57
Sell Slaughter Steer:	6.32	1E+30
Sell Wheat:	25.03	.55
Sell Oats:	.69	1E+30
Pasture Transfer from 1st-2nd Season:	4.81	1E+30
Pasture Transfer from 2nd-3rd Season:	4.81	2.58
Pasture Transfer from 3rd-4th Season:	4.61	1.27
Pasture Transfer from 4th-1st Season:	4.76	1.7

Figure 4.14 The Solution Report of the Sensitivity Analysis (in Plain Text)

CHAPTER V

SUMMARY AND CONCLUSION

Farm Planning Model has been a topic of farm and agribusiness management for many years. It is used to determine optimal allocation of a farm's limited resources such as land, labor and capital among alternative crop and livestock enterprises. It helps farmers to decide what and how much will be produced to make the optimal returns from available resources. Agricultural economists have developed several software systems to solve the Farm Planning Model in the past. There are also other software systems available to solve the farm Planning problem. Since the algorithm behind the Farm Planning Model is linear programming, all of these software systems are relatively complex and require certain levels of computer skills and knowledge of linear algebra and agricultural economics background. This kind of inconvenience prevents farmers from using these systems. This study is to develop a windows-based easy-to-use software system for the farmers to solve farm planning problem themselves. The system is called Farm Planning Model System.

The Farm Planning Model System developed in this study includes four parts: the farm planning data sheets, the farm planning model, the farm planning solver and the sensitivity analysis. The farm planning data sheets allow the users to enter the relevant information of the farm planning problem (such as the amounts of resources and the prices of products and so on). The farm planning model generates the objective function and the constraint matrix for the farm planning problem automatically from the information the users enter in the farm planning data sheets. The farm planning solver solves the farm planning problem to return the optimal solution back to the same constraint matrix generated in the part of the farm planning model. The optimal solution provides the users with the optimal value for the farm planning problem and its associated allocation of the products produced and the resources used. The sensitivity analysis gives the ranges of variation of these coefficients for which the optimal solution remains optimal. The farm planning model system is implemented using Visual Basic 5.0 under the Windows 95 environment.

The Farm Planning Model System is applied to a real Farm Planning problem. The solution of the System is compared to those of MUSAH86 and Microsoft Excel linear programming module, and the results are the same.

The Farm Planning Model System has the following advantages:

(1) Easy-to-use. Any farmer with basic Windows skill can use this system.

(2) Cost efficiency. The software requirements are only Windows 95 and Visual Basic 5.0.

An extension of the sensitivity analysis is expected in the future work of this farm planning model system.

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Appendix 1

Installation Procedure for the Farm Planning Model System

1. Hardware and Software Requirements

Hardware: CPU with speed of 133 mhz or above.
CPU with Random Access Memory (RAM) of 16 MB or more.
CPU with spare disk space of at least 40 MB.
SVGA color minitor.
IBM compatible keyboard.
IBM compatible mouse.

Software: Windows 95 / 98 / NT operating system.
Microsoft Visual Basic 5.0 or above compiler.

2. Installation and Operating Procedure

The Farm Planning Model System is about 1.6MB and in two floppy disks.
Installation Procedure:
Copy all files from Disk 1 and Disk 2 into the hard drive.
Operating Procedure:
Step 1. Open the project file and run the program (just click the "► " icon).
Step 2. Open data sheets (input data).
Step 3. Farm Planning Model (in Matrix Form) is generated automatically after you input the data sheets.
Step 4. Click solver to solve the program.
Step 5. Solution Reports (Solution Report in Matrix Form and Solution Report in Plain Text Form) are returned.
Step 6. In order to do sensitivity analysis, click the "Sensitivity Analysis" in the menu, then click the "Adjustable cells", the Sensitivity Analysis Reports (Sensitivity Analysis Report in Matrix Form and Sensitivity Analysis Report in Plain Text Form) are Returned.

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